ZOOPLANKTON STUDIES AT THE DONALD C. COOK NUCLEAR PLANT: 1979-1982 INVESTIGATIONS, INCLUDING PREOPERATIONAL (1971-1974) AND OPERATIONAL (1975-1982) COMPARISONS

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SUMMARY

This report contains the results of investigations conducted between January 1979 and May 1982 evaluating the impact of the operation of the cooling water system of the Donald C. Cook nuclear power plant on zooplankton populations in southeastern Lake Michigan. The report presents the results of two basic programs: the lake survey program and the entrainment program. Lake studies were designed to provide information on the extent of the thermal plume and the effects of thermal discharges on zooplankton community structure. Spatial effects and long-term changes in zooplankton community structure were investigated. The entrainment program was designed to assess the effects of plant passage on zooplankton mortality.

Temperature and Secchi disc depths were measured during 26 monthly surveys (April to November 1979-1981 and April to May 1982). Ambient surface-water temperatures ranged from less than 2°C to over 24°C. While water temperatures were similar in the four years, some differences did occur, particularly in spring. Surface-water temperatures were a few C° higher in April and May 1981 than in 1979 and 1980. May 1982 surface-water temperatures were also higher than in 1979-1981. An upwelling was observed during the September 1980 cruise.

The thermally-detectable plume (ΔT 0.5 C°) was limited to a comparatively small area (<3 km^2) of the survey grid (250 km^2). Condenser-passed water was diluted within minutes to 30% of its original concentration by mixing with lake water. This intense mixing in the vicinity of the discharge jets facilitated the rapid cooling of condenser-passed water.

Secchi disc depths ranged from less than 1 m to over 10 m with the highest values occurring in summer. There was no evidence of decreased Secchi disc depths in the vicinity of the thermal plume.

Monthly lake surveys conducted in 1979, 1980, and 1981 (April to November) and 1982 (April and May) provided information on zooplankton distribution over the 250 km^2 area of the survey grid during plant operation. Zooplankton seasonal and spatial distribution patterns (numbers, percent composition, biomass) generally were similar to those observed in preoperational years. No evidence of gross alterations in zooplankton populations in the vicinity of the thermal plume was found during any of the twenty-six cruises.

Daphnia parvula, a species first observed in 1978, was observed at a few stations in May 1979 but was not observed again during the 1979-1982 period. This species typically is associated with ponds and small lakes in more southern locales. *Mesocyclops edax*, a cyclopoid copepod, which was collected in relatively high numbers during the October and November 1978 cruises, was collected infrequently during the 1979-1982 period. *Daphnia pulicaria* (formerly referred to as *Daphnia pulex*; Evans et al. 1980, 1982) was observed at several stations during fall cruises (September-November) in the 1979-1981 period, and during April and May, 1982. *Daphnia pulicaria* is a relatively large zooplankter and is particularly susceptible to fish predation. Increased densities of this species appear to be related to changes in fish community structure in southeastern Lake Michigan, especially the decrease in alewife abundances.

As in the previous report (Evans et al. 1982), variations in zooplankton distribution over the survey grid were investigated by using principal

component analysis. Depth was identified as the most consistent correlate of overall abundance patterns of zooplankton. The major survey grid, consisting of thirty stations sampled during April, July, and October of each year, was divided into four depth-related regions: an inner region between the 5- and 10-m depth contours, a middle region between the 10- and 20-m depth contours, an inner offshore region between the 20- and 30-m depth contours, and an outer offshore region extending beyond the 30-m depth contour to approximately the 45-m depth contour. During July and October, zooplankton tended to be least abundant in the inshore region and to increase in abundance with depth out to the 20- to 30-m depth contour; abundances levelled off or decreased slightly with greater distance from shore. Zooplankton differed in composition with distance from shore (depth); the inshore region was dominated by small zooplankton, while larger cladocerans and copepods tended to increase in dominance with increasing station depth. This trend is most probably due to greater fish predation intensity in the inshore region.

Prior to comparing preoperational and operational densities of zooplankton, the survey grid was divided into eight zones. The inshore and middle regions were each divided into three zones: a plume zone extending 1.6 km north and south of the plant site, and north and south control zones. Within the inshore and middle plume zones, the seasonal patterns of abundance of the major taxa generally were similar during preoperational and operational years. For the most part, the range of population densities observed in the preoperational period was not exceeded in the operational period. Exceptions were adult Diaptomus spp., Eurytemora affinis copepodites, and Eubosmina coregoni; their maximum attained abundance in the operational period was 1.5 to 5 times that observed in the preoperational period. Differences were also

observed in other zones of the survey grid and probably were related to factors such as differences in seasonality between years, eutrophication, or changes in fish community structure.

Comparisons of zooplankton densities between the preoperational (1971-1974) and operational (1975-1982) periods by major survey month (April, July, October) and by zone (a total of eight) indicated that many taxa occurred in significantly ($P < 0.05$) different concentrations before and during plant operation. For the April analyses, zooplankton tended to be more abundant in the operational period, with the greatest increase in numbers associated with copepod nauplii, immature and adult *Diaptomus* spp. adults, and *Limnocalanus macrurus* copepodites. For July analyses, zooplankton taxa tended to be equally or less abundant in the operational period with the exception of *Daphnia* spp., which were more abundant. In October, zooplankton tended to be more abundant in the operational period, with increased abundances of copepod nauplii, and immature *Cyclops* spp. and *Diaptomus* spp. copepodites. However, *Daphnia* spp. and adult *Cyclops* spp. tended to be less abundant.

While preoperational-operational differences in zooplankton abundance tended to be detected more frequently in the inshore and middle plume zones than in the six control zones, differences of similar magnitude were observed in plume and control zones. Since the preoperational and operational differences were not localized in the immediate discharge area, they cannot be readily attributed to the direct impact of the power plant on zooplankton populations in the vicinity of the plant.

Percentage zooplankton mortalities as a result of plant passage were low in most months, averaging, at 0-hour, 10.2% in the intake forebay, 11.4% in Unit 1 discharge, and 13.4% in Unit 2 discharge forebay waters. High

mortalities were observed in intake waters during several months of the 1979-1982 period, which may have been due to resuspension of detrital zooplankton in the vicinity of the intakes.

Statistical analyses were performed by month and taxon to investigate whether or not zooplankton mortality was significantly greater in discharge than in intake waters. Several significant differences were detected, with no clear seasonal pattern of mortality differences. Further analyses were performed utilizing the mortality data for the 1975-1982 period. For the 0-hour, 6-hour, and 24-hour incubation periods, calanoid copepods were the major taxa exhibiting significantly higher mortalities in discharge than in intake waters, although Daphnia spp. and Eubosmina coregoni also exhibited significant differences. The mean monthly difference between intake mortalities and Unit 1 discharge mortalities for taxa which exhibited significant differences ranged from 1.6% to 9.6%. Unit 2 discharge mortality differences for taxa exhibiting significant differences ranged from 2.1% to 9.0%. Overall, mortalities were not significantly related to discharge water temperature or ΔT. However, the results of the earlier September 1978 mortality study suggest that mortalities would increase substantially were discharge water temperatures to exceed 35°C. Season affected significant mortality differences only in that differences were more easily detected during months when taxa were abundant. Zooplankton greater than 1.5 mm length appear to be more susceptible than smaller taxa to damage during plant passage.

Millions of zooplankton passed through the plant each second. The estimated biomass entrained each month ranged from 1,117 kg dry weight in March 1982 to 21,991 kg dry weight in November 1981 and averaged 8,191 kg/

month. The estimated maximum biomass loss (based on the assumption that the discharge mortality represented an upper limit of mortality loss) ranged from 70 kg/month (October 1981) to 4,482 kg/month (July 1979), and averaged 1,135 kg/month. More zooplankton were entrained during the 1977-1982 period than in the 1975-1976 period due to the greater abundance of zooplankton and higher cooling-water utilization rate in 1977-1982. It is unlikely that the presence of detrital zooplankton produced as a result of plant passage adversely affected water and sediment quality in the discharge area. Currents prevent the accumulation of such material in the vicinity of the plant.

Field survey data and entrainment data were analyzed to determine the representativeness of the power plant as a sampling location for zooplankton populations within the 10-m depth contour. The correlation between abundance in entrainment and lake collections was significant for total zooplankton and most of the seasonally dominant taxa. The exceptions were immature and adult *Cyclops* spp. copepodites. These taxa have epibenthic affinities and live in high concentrations in close proximity to the sediments in addition to inhabiting the water column. These taxa occurred in relatively high concentrations in the cooling waters, suggesting that the power plant entrained significant amounts of water from the sediment-water interface. Overall, the analyses suggest that the power plant intakes can serve as a representative sampling location for investigating long-term trends in zooplankton populations in the inshore region.

This report interrelates the results of several studies conducted at the Donald C. Cook Plant over the 1979-1982 period and utilizes the 1975-1978 operational and the 1971-1975 preoperational data. It provides an overview on the effects of plant operation over a 250 km^2 area of southeastern Lake

Michigan. The results of the study indicate that the effects of power plant passage on the zooplankton community of Lake Michigan appear to be minimal. The zooplankton mortalities that occur as a result of entrainment in cooling water are virtually undetectable in the lake due to the rapid dilution of discharged water. Changes in zooplankton community structure over the monitoring period are most likely due to factors other than long-term power plant effects.

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INTRODUCTION

The Donald C. Cook Nuclear Plant is a two-unit plant which, at full operational capacity, produces 2,200 MWe. While the plant is only one of nearly fifty nuclear and coal-fired plants on Lake Michigan, it is one of the largest. The Zion plant, located north of Chicago, is the only other operating, similar-sized plant.

At full operational capacity, the Donald C. Cook Nuclear Plant utilizes approximately 6,300 m^3 of lake water each minute for its once-through cooling system. This rate is equivalent to the mean annual flow rate of any one of the four largest rivers (Fox, St. Joseph, Grand, Menominee) discharging into Lake Michigan (U.S. Department of the Interior 1968).

Zooplankton entrained with lake water into the power plant are exposed to a temperature increase of up to 12 C° for a period of approximately three minutes prior to discharge back into the lake. Zooplankton continue to be exposed to thermal elevations as the plume water gradually mixes with (and is cooled by) ambient lake water. Calculations of the thermal decay along the plume centerline for the plume produced by Unit 1 (United States Atomic Energy Commission 1973) provide an estimate of exposure times for those zooplankton entrained into the plume. Using these calculations and applying them to two-unit operation, zooplankton exposure times to temperatures 2.8 C° (5 F°) above ambient are in the order of 20 minutes while exposures to temperatures 1.7 C° (3 F°) above ambient are in the order of 142 minutes.

Power plants, by utilizing water for their various cooling systems (once-through, cooling ponds, cooling towers), can potentially adversely affect the receiving water body, including the biota. Thus, power plants are subject to

various licensing requirements. One of these, section 316(a) of the Federal Water Pollution Control Act, requires that the thermal component of plant effluent be such that it will "assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water". The other, section 316(b), requires the application of the best available technology so that the location, design, construction, and capacity of such structures will minimize adverse environmental impacts.

The Donald C. Cook Nuclear Plant, in order to fulfil its licensing requirements, was required to demonstrate that plant operation satisfied the conditions described in the 316(a) and 316(b) statements. Probably because of the size of the plant, monitoring studies conducted in and around the plant site were detailed and long-term. Such studies extended from 1969 to 1982 and included phytoplankton, zooplankton, benthos, and fish investigations in addition to less detailed studies of ice-formation, bacteria, sediments, and water chemistry. The results of these studies appear in a series of Great Lakes Research Division reports and in various scientific publications.

This report addresses the effects of the operation of the once-through cooling system of the Donald C. Cook Nuclear Plant on zooplankton populations in southeastern Lake Michigan. The report focuses on the 1979-1982 period but also considers the entire (1975-1982) operational period. The zooplankton monitoring investigation was completed in May 1982; thus, this is the final report.

The main body of this report consists of four sections. The first section describes zooplankton distributions over the survey area during the 1979-1982 period, and the associated thermal and Secchi disc characteristics of the water column. This section is descriptive in nature and serves as a

summary record for the various cruises. These data are examined to determine the extent of the thermal plume. Furthermore, they are examined to determine whether or not there was any evidence of gross alterations in zooplankton community structure in the vicinity of the plume. Finally, analyses are conducted of major survey data (April, July, and October) to determine the basic components of spatial gradients in zooplankton community structure.

In the following section, comparisons are made of the seasonal patterns of zooplankton abundance in the immediate discharge area before and during plant operation. Furthermore, statistical comparisons are made of zooplankton abundances in the preoperational and operational periods for plume and control stations of the survey grid.

The third and fourth sections of the report focus on the direct effects of condenser passage on entrained zooplankton. In Section 3, the mortality levels of zooplankton passing through the plant are presented and related to water temperature (intake, disharge, ΔT). These data are statistically analyzed to investigate whether or not plant passage significantly affects zooplankton mortality. In the fourth section, the numbers and biomass of zooplankton passing through the condenser cooling system are estimated. In addition, the numbers and biomass of zooplankton killed during plant passage are estimated. The report ends with a series of concluding remarks evaluating the effectiveness of the Donald C. Cook Nuclear Plant in meeting 316(a) and 316(b) requirements with respect to zooplankton populations.

SECTION 1

THE SEASONAL AND SPATIAL DISTRIBUTIONS OF ZOOPLANKTON DURING THE 1979, 1980, 1981, AND 1982 SURVEY CRUISES

INTRODUCTION

Freshwater zooplankton are small animals, usually less than 2 mm in length. Whether weak or strong swimmers, some constraint is placed on their swimming velocity by size. Average swimming velocities for most species are much less than 1 cm/sec. This compares with water currents having velocities several times to orders of magnitude greater. In this sense zooplankton are, as suggested by the Greek root planktos, wanderers entrained by currents and carried from one region to another. However, the implication that zooplankton are randomly distributed in a lake due to currents, is not entirely true. Their swimming ability is often adequate to maintain them at a given depth, and to allow patterned vertical movement in a water column. This migratory swimming is most likely related to feeding and predation avoidance (Zaret and Suffern 1976).

Zooplankton are a major constituent of the aquatic food web. They feed as herbivores, omnivores, or carnivores, and are themselves food for fish, and other vertebrate and invertebrate planktivores. Research has demonstrated the links between nutrient input (roughly equivalent to the state of eutrophication), phytoplankton density and zooplankton density, as well as those between planktivores and zooplankton community structure (Hrbacek 1962, Brooks and Dodson 1965, Patalas 1972, McNaught and Buzzard 1973, McNaught 1975, Pederson et al. 1976). The link between phytoplankton and zooplankton

is two-way. Besides being affected by phytoplankton abundance, zooplankton may influence phytoplankton composition through selective grazing and nutrient recycling. Furthermore, the intensity of vertebrate planktivory affects the phytoplankton community as well as zooplankton. Changes in phytoplankton communities may occur in response to planktivore-induced variations in zooplankton grazing pressures (Scavia et al. 1986).

Our sampling methods (156-μm-mesh nets) result in zooplankton collections dominated by crustaceans, mainly copepods and cladocerans, which generally range in size from 0.2 to 2.0 mm in length. Rotifers, the third major component of Great Lakes zooplankton are smaller than most crustacean zooplankton. Consequently, they are most efficiently collected by nets of 76-μm mesh and smaller.

Life-history strategies vary among the crustacean zooplankton. In most instances, Cladocera reproduce parthenogenetically. The all-female populations are ovoviviparous. Eggs are retained in the brood pouch where they develop into the first immature stage. Immature Cladocera, which are morphologically similar to adults, develop through two or more instars before the adult stage is reached. Generation times are several days to weeks, dependent on cladoceran species, food abundance, and temperature. Cladocera are able to quickly take advantage of increased food supplies with this reproductive strategy. Copepods reproduce sexually. After hatching from the egg, an individual develops through six nauplius stages and six copepodite stages with the sixth being the adult. Generation times range from several days for some species, to a year or more for others. In Lake Michigan, most copepods produce one to three generations per year (Torke 1975).

Total zooplankton abundance (as determined with 156-μm mesh net collections) varies seasonally over the survey area from less than 1,000/m^3 (late winter minimum) to over 200,000/m^3 (mid-summer maximum). Copepods are the numerically dominant taxon during winter and spring while copepods and cladocerans are dominants during summer and autumn. Spatial variations in abundance, while smaller than temporal variations, are significant. Factors which have been implicated as significant in producing spatial variability include phytoplankton abundance and composition, fish predators, invertebrate predators, and intraspecific and interspecific competition. Physical events such as upwellings can alter zooplankton assemblages in an area in a matter of hours, replacing epilimnetic zooplankton with metalimnetic and hypolimnetic species.

The main influences on zooplankton survivorship are food abundance and predation intensity. Cultural eutrophication, the accelerated "aging" of a lake through increased input of nutrients, is a well studied process (R. G. Wetzel 1975). Documented effects of eutrophication are an increase in primary production, and the replacement of "desirable" by "undesirable" algae, mainly bluegreens. Changes in phytoplankton community structure, along with other eutrophication-related changes may alter zooplankton community structure (Brooks 1969, Patalas 1972).

The most throughly investigated factor affecting zooplankton community structure is fish predation. Planktivorous fish, in general, prey selectively on the largest available zooplankton (Brooks 1968, Galbraith 1967, Zaret 1980). Size-selective predation may reduce or eliminate populations of large animals, skewing the community toward dominance by small species.

Lake Michigan has been affected by cultural eutrophication (Beeton 1969, Chapra and Robertson 1977), especially through increased phosphorus input. With the implementation of nutrient abatement programs, this process has decelerated (Makarewicz and Baybutt 1980). Major changes also have occurred in planktivorous fish populations, as the alewife (Alosa pseudoharengus) replaced indigenous species (Christie 1974). Fluctuations in alewife predation were a likely cause of documented changes in offshore zooplankton community structure (Wells 1970). Eutrophication also may have caused some of these changes (Brooks 1969). In scale, eutrophication and alterations in fish populations may have lake-wide effects on zooplankton community structure and thus be easily detectable. The consequences of another human influence, thermal pollution from power plant cooling waters, are not as well known. Power plant operation may adversely affect (through thermal and mechanical stresses) those zooplankton which pass through the condenser cooling system. Furthermore, zooplankton entrained into the thermal plume may be adversely affected. Unlike effects due to cultural eutrophication and alterations in planktivorous fish standing stocks, power plant effects are more likely to be regional.

In the late 1960's and early 1970's there was concern that increased power plant construction on Lake Michigan shores, with the ensuing substantial usage of lake water for condenser cooling, would have detrimental effects on lake biota, including zooplankton. Monitoring programs were designed to determine these effects, with the size of the program proportional to power plant size. The Donald C. Cook Nuclear Plant, one of the largest plants on Lake Michigan, has had a particularly large monitoring program. The lake sampling program, which includes a large survey grid and several years of

preoperational (1970-1974) and operational (1975-1982) monitoring, was designed to investigate the effects of power plant operation on zooplankton community structure over a substantial area of the lake.

Preoperational studies have determined the major limnological features of this area. Water tends to flow in a northerly direction, parallel to shore, but does flow in other directions depending on meteorological events. The Michigan City-Benton Harbor eddy lies in the outer half of the survey area during parts of spring, summer, and autumn (Ayers et al. 1958, 1967). Nutrient-enriched water enters the survey grid from the north (St. Joseph River) and from the south. Enriched water also enters the survey grid from the Bridgman sewage plant (3 km south of the plant site) and from streams south of Warren Dunes State Park. Differences in water flow and chemistry have resulted in both along-shore and inshore-offshore differences in sediment composition (Rossmann 1975).

Macrobenthic populations vary in abundance and composition with distance from shore and, to a lesser extent, along shore (Mozley 1973, 1974, Johnston 1973). Spatial differences also occur in fish populations inhabiting southeastern Lake Michigan (Wells 1968, Jude et al. 1975).

Phytoplankton populations (collected from 1-m depth) exhibit inshore-offshore differences in abundance (Ayers 1975). Zooplankton (collected from the entire water column) exhibit pronounced inshore-offshore differences in abundance (Evans et al. 1980) and biomass (Hawkins and Evans 1979) in most months. Phytoplankton and zooplankton exhibit less consistent along-shore differences in abundances.

This section describes zooplankton distributions in 1979, 1980, 1981, and 1982 over the survey grid. It also presents the results of additional

analyses of depth-related differences in zooplankton assemblages. The thermal characteristics of the water column, the location of the thermal plume, and the Secchi disc depths are presented for each cruise.

MATERIALS AND METHODS

Survey Grid

The survey grid (Fig. 1) extended 11 km north and south of the plant site and 11 km offshore. The closest power plant south of the Donald C. Cook Nuclear Plant is the Michigan City Generating Station (34 km), a 203 MWe plant which utilizes both a cooling tower and once-through cooling. To the north (55 km) is the Palisades Nuclear Power Plant, a 811 MWe facility (Krezoski 1969) which employs cooling towers.

Major surveys and short surveys (Fig. 1) were conducted monthly from April through November, 1979-1981 and in April and May 1982, when the sampling program was discontinued. Major surveys consisted of 30 stations and provided detailed information on zooplankton populations during the spring (April), summer (July), and autumn (October). Short surveys consisted of 14 stations and provided information on zooplankton population dynamics during the intervening months.

The original (1970) survey grid consisted of 46 stations. The final (1973-1982) monitoring program consisted of 14 or 30 station subsets of the original grid. A two-part numbering system was used to name each station. The first part, DC, NDC x, or SDC x, referred to the location of a transect relative to the plant site. The DC transect extended directly offshore of the plant, and the NDC x and SDC x transects were respectively 0.5, 1, 2, 4, or 7 miles north or south of the plant site. The second part of each station name

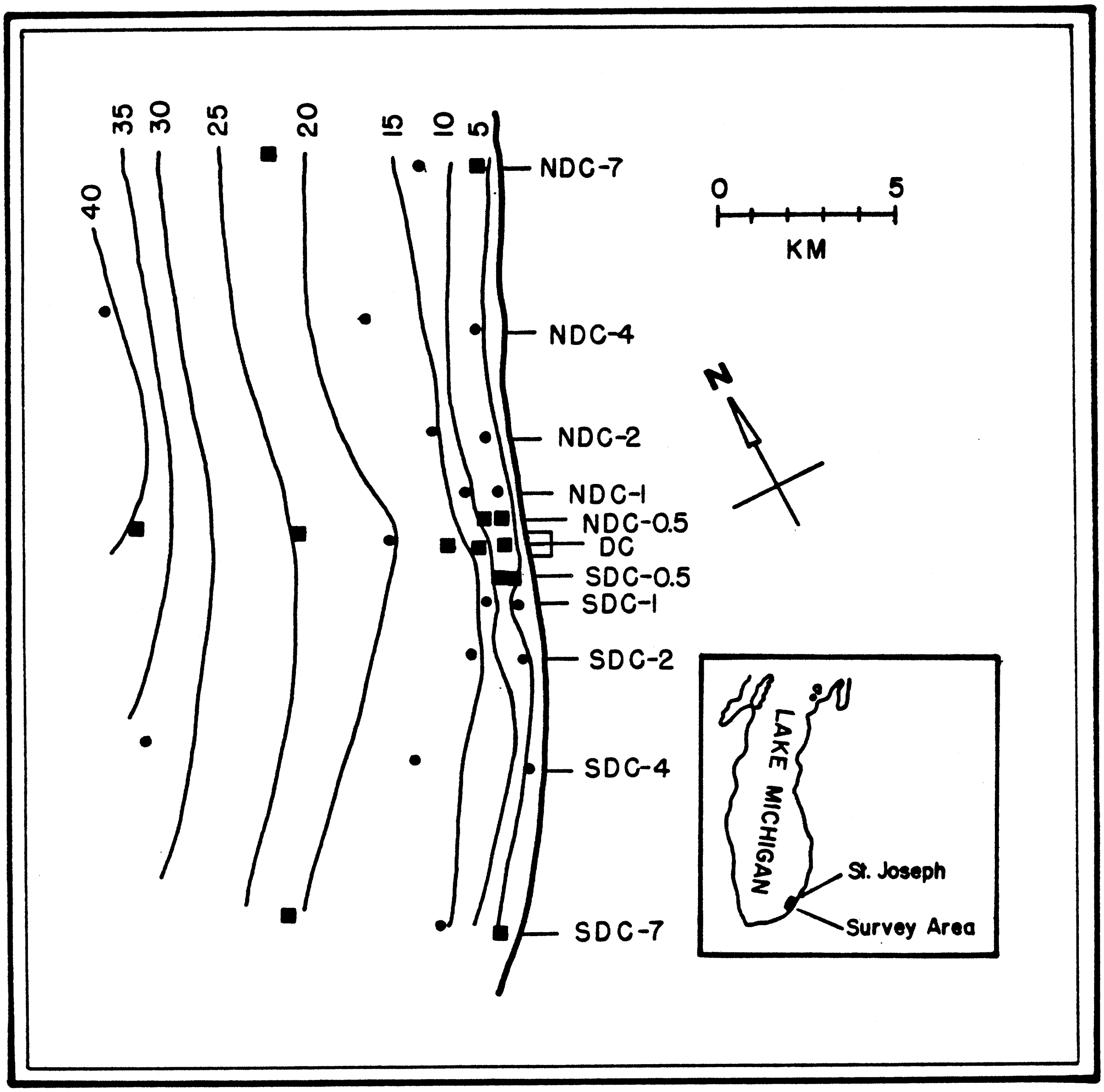


Fig. 1. Station locations for the major surveys. Squares indicate the subset of short survey stations. Depth contours are in meters.

designated the station number in a transect series. For example, DC-1 was the first station along the DC transect (and closest to shore) while DC-6 was the sixth station along the transect. DC-6 is as far offshore as NDC 4-4, the fourth station in the NDC 4 transect.

For the major survey cruise grid (Fig. 1) the six stations along the DC transect were retained, stations 1 and 2 of the original three of the NDC 1 and SDC 1 transects, stations 1 and 3 of the original three of the NDC 2 and SDC 2 transects, stations 1, 3, and 4 of the original four of the NDC 4 and SDC 4 transects, and stations 1, 3, and 5 of the original five of the NDC 7 and SDC 7 transects. The short survey grid consisted of a subset of the major survey grid.

Station depths ranged from 4 m to over 40 m and increased with distance from shore (Fig. 1). The three intake pipes utilized by the power plant are located approximately 690 m offshore (between stations DC-1 and DC-2) in 7.3 m of water at the apices of a 75 m equilateral triangle. Two discharge pipes return heated water to the lake with the northern pipe servicing Unit 1 and the southern pipe Unit 2. The two pipes are located approximately 380 m offshore (station DC-1) in 5.5 m of water and are 100 m apart.

Physical Measurements

Surface-water temperatures were measured at each station with a thermometer immersed in a bucket of freshly collected water and/or with a YSI thermistor probe suspended a few centimeters below the water surface. Temperature-depth profiles were determined with an electronic bathythermograph and a chart recorder. Temperature could be read with a precision of ± 0.5 °C and depth to ± 0.25 m. At each station, both ascending and descending traces

were recorded and the average calculated. Traces were not obtained at all stations due to malfunctions in the electronic bathythermograph. At those times, a 200-foot (94.5 m) mechanical bathythermograph generally was used.

Secchi disc depths were measured using an 8-inch (20.3 cm) diameter white disc. Water color was also noted. Data are missing from stations sampled after sunset. For the seven cruises during which this occurred, generally only two or three stations were affected.

Zooplankton Sampling Methods

Zooplankton were collected at each station with 50-cm diameter nets. Prior to 1979, three replicates were taken with a 156-μm mesh net according to the Technical Specifications for the zooplankton studies. Beginning in May 1979, the third replicate was collected with a 76-μm mesh net. Samples collected in 1979 were examined for rotifers, which comprise an important part of the zooplankton, and were used to investigate the loss of smaller organisms (i.e., nauplii) through the larger mesh nets. The results of these studies are discussed in Stemberger and Evans (1984) and Evans and Sell (1985).

A calibrated flowmeter mounted in the mouth of each net measured the volume of water filtered during each vertical haul. At each station, nets were hauled from as close to the bottom as possible (about 1 m) to the surface. The flowmeter was read, the outside of the net washed down, and the contents of the plankton bucket transferred to a labelled jar. Samples were preserved with Koechie's fluid, a sugar-formalin solution (2.3 kg sugar dissolved in 2 L of formaldehyde, and 8 L of water) (Haney and Hall 1970). Tonic water was added to each third net haul (76-μm mesh net) to relax soft-

bodied rotifers. These samples were allowed to stand for several minutes before Koechie's fluid was added.

Counting Techniques

In the laboratory, zooplankton in the first two replicate samples (156-μm mesh net) from each station were examined for cladocerans and copepods. Selected third samples (76-μm net) were examined for rotifers and crustacean zooplankton. The third samples studied were from May to November 1979 for stations DC-2, DC-3, DC-5, DC-6, NDC-.5-1, and SDC-.5-1. Results of these studies are reported in Stemberger and Evans (1984) and Evans and Sell (1985).

Each sample was subdivided as many times as necessary in a Folsom plankton splitter to give two subsamples of 300 to 600 organisms each. A third subsample of 600 to 1200 organisms was examined for rare taxa (less than 40 animals in the summed subsample counts). Cladocerans and adult copepods were identified to species level, and adult copepods distinguished by sex at all stations. Immature copepodites were identified to genus while nauplii were combined as a group. Asplanchna spp. was the only rotifer enumerated. Taxonomic keys referred to included Pennak (1963), Deevey and Deevey (1971), Stemberger (1979), Brooks (1957, 1959), Wilson (1959), Tressler (1959), and Yeatman (1959).

In 1978, two apparent species of Daphnia were newly observed over the survey area. These Daphnia appeared to belong to the pulex complex. As the taxonomy of this complex is not well understood, the separation of species was difficult. The newly observed Daphnia were tentatively identified as D. pulex and D. schødleri. After a recent, thorough review of the animals and the literature (Grogg 1977, Brandlova et al. 1972, Pennak 1978, Brooks 1959), the

two taxa have been determined to be morphological variants of the same species and are designated D. pulicaria (Evans 1985).

Zooplankton were enumerated in a circular counting dish using a stereomicroscope at a magnification of 20 to 140X. A compound microscope was used to verify certain species identifications and to identify species whose occurrences in the survey area had not been noted previously. In these instances, past collections were re-examined for the presence of these species.

Dry Weight Determinations

Each month, triplicate weight measurements were made with a Cahn electrobalance (accurate to ± 0.5 μg) for groups of 3 to 30 preserved animals from each of the numerically dominant taxa. Before weighing, the animals were washed in distilled water, placed in preweighed aluminum boats (0.5 cm diameter) and desiccated for at least 48 hours over silica gel absorbent at room temperature.

Biomass was determined for most taxa from samples collected at DC-1 and DC-6. When taxa were rare at one of the two stations, biomass estimates were based on determinations made at only one station. A few taxa, generally less than 5% of total zooplankton, were so rare that their dry weights were not determined. No consistent differences in mean dry weight of the various taxa between the two stations were observed so the results were averaged to obtain a mean biomass estimate for each taxon over the survey grid during a particular cruise. An estimate of zooplankton standing stock (mg dry weight/ m^3) was calculated by summing the product of the mean biomass (μg/individual zooplankton taxon) and the density estimate (number/m^3) for each taxon. The

mean dry weight per individual at each station was calculated by dividing the total sample biomass by the sample numerical density. Additional information on copepod dry weights appears in Warren et al. (1986).

Principal Component Analyses

We have used principal component ordinations on the 1972-1978 field survey data to identify groups of stations with similar zooplankton abundances and compositions. Stations generally clustered together along a depth gradient, suggesting that factors related to depth are important in determining zooplankton distributions over the survey area. Four depth regions were identified: the inshore region (between the 5- and 10-m depth contours), the middle region (10- to 20-m depth contours), the inner offshore region (20- to 30-m depth contours) and the outer offshore region (30- to 50-m depth contours) (Evans et al. 1980). Stations within or close to the thermal plume generally clustered with other, inshore-region stations.

We performed similar ordinations using the April, July and October 1979, 1980, and 1981, and April 1982 major cruise data. When possible, we used the same taxa in a seasonal analysis as used in previous analyses. However, year-to-year differences in the abundances of rare taxa caused minor alterations in the taxa selected for the analyses.

Analyses were performed by utilizing the variance-covariance matrix of the log-transformed (numbers/m^3 + 1) taxa data. Generally if a taxon accounted for at least 1% of the zooplankton at several stations for a month it was used in an analysis. Six taxa were used for the April analyses, 9 for the July 1979 and 1981 analyses, 11 for July 1980, and 10 for the October analyses. Correlations between the principal components and the log-

transformed original variates were performed to assist with the interpretation of the principal components. The analyses were performed using the Michigan Interactive Data Analysis System (MIDAS), a statistical package implemented on the University of Michigan computing system.

The major purpose of these analyses was to determine whether or not spatial gradients in zooplankton community structure over the 1979 to 1982 period were similar to those observed during the preoperational (1972-1974) and previous operational (1975-1978) periods. Furthermore, these analyses provided us with a second method for comparing zooplankton community structure in the thermal plume and ambient inshore waters.

RESULTS

Survey Cruise Characteristics

This section summarizes the major physical features of the survey area, including the extent of the thermal plume, during each cruise. Furthermore, it presents the major features of zooplankton community structure during each cruise. Major survey cruise data are examined to determine whether or not there was any evidence of gross alterations in zooplankton community structure in the vicinity of the thermal plume. As in previous reports (Evans 1975, Evans et al. 1978a, 1980), we present survey cruise data by month across the 1979-1982 study period. This allows us to more efficiently compare zooplankton community structure across years and complements the preoperational-operational comparisons of April, July, and October data which are presented in Section 2.

12 April 1979

Surface-water temperatures ranged from 1.3 to 6.1 °C with the thermal bar approximately 0.7 km offshore (Fig. 2a). The thermal plume was small and weakly defined (Fig. 2a). The water column was thermally well mixed (Fig. 2a). Secchi disc depths (Fig. 3a) ranged from 0.7 m to 7.1 m with offshore values greater than inshore values. Water color was generally murky green at inshore stations and clear green at deeper (>22 m) offshore stations. Total zooplankton concentrations ranged from 3,740 to 7,530/m^3 (Fig. 4a). Abundances were slightly higher in the inshore than the offshore region.

Copepod nauplii (Fig. 4e) and adult *Diaptomus* spp. (Fig. 4u) (primarily *D. ashlandi*) were the numerically dominant taxa. Nauplii accounted for more than 50% of the zooplankton in the inshore and middle regions. Adult *Diaptomus* spp. (primarily *D. ashlandi*) comprised over 30% of the population in all depth regions. Other abundant taxa included adult *Cyclops bicuspidatus thomasi* (Fig. 4m) and *Limnocalanus macrurus* (Fig. 4y). Immature *Diaptomus* spp., *Cyclops* spp., and *L. macrurus* copepodites generally were less abundant than adults. While most taxa were more abundant in the shallow inshore regions than offshore, immature *Cyclops* spp. copepodites occurred in greater numbers in deeper waters (Fig. 4i). Cladocerans were rare over the survey area; *Bosmina longirostris*, *Eubosmina coregoni*, and *Chydorus sphaericus* were the most frequently encountered species.

Biomass ranged from 7.4 to 31.3 mg/m^3 (Fig 5a). Adult *Diaptomus ashlandi*, *D. sicilis*, and *Limnocalanus macrurus* accounted for most of the biomass over the survey area.

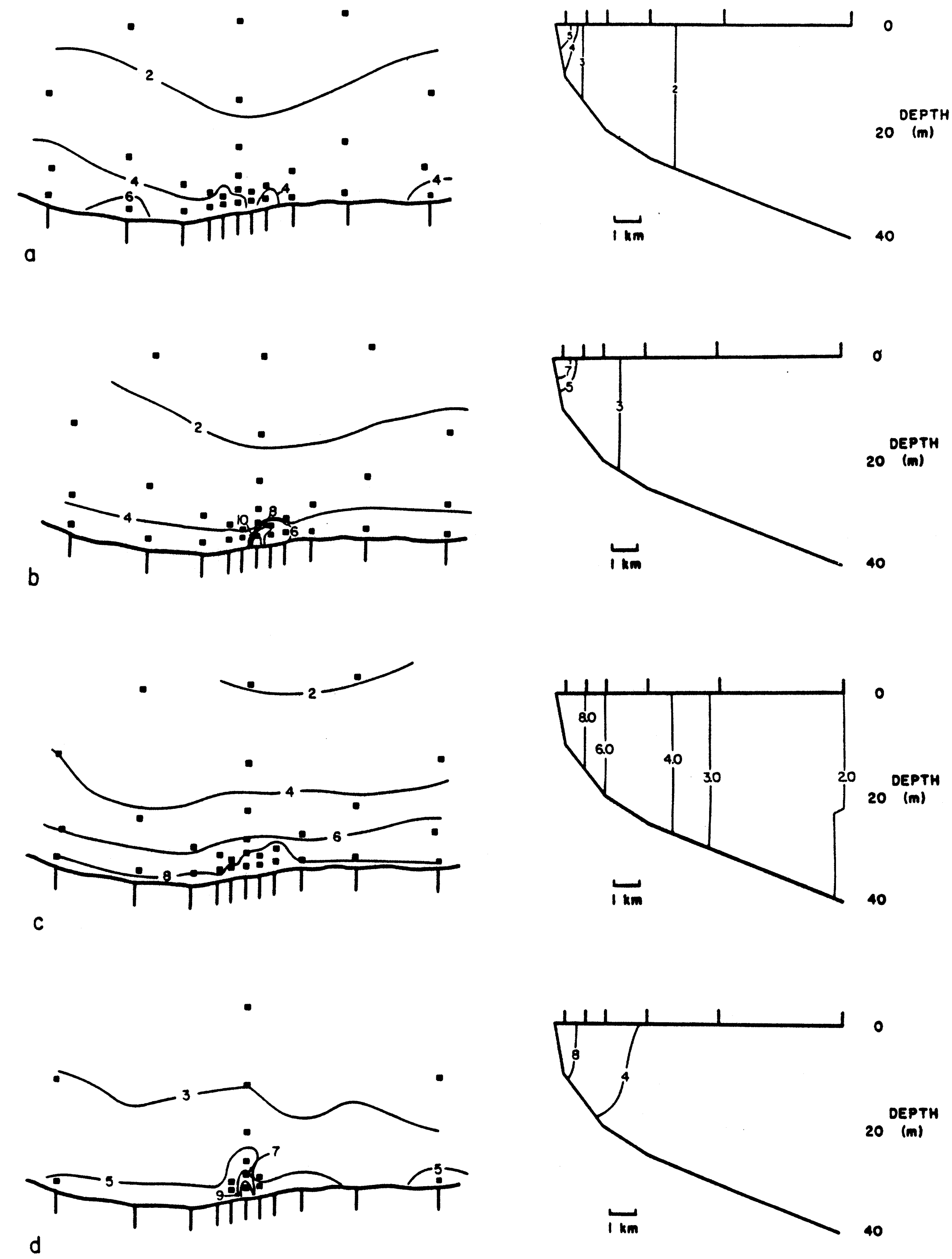


Fig. 2. Surface water temperature (left column) and temperature-depth profiles along the DC transect (right column) on a) 12 April 1979, b) 10 April 1980, c) 10 April 1981, d) 15 April 1982,

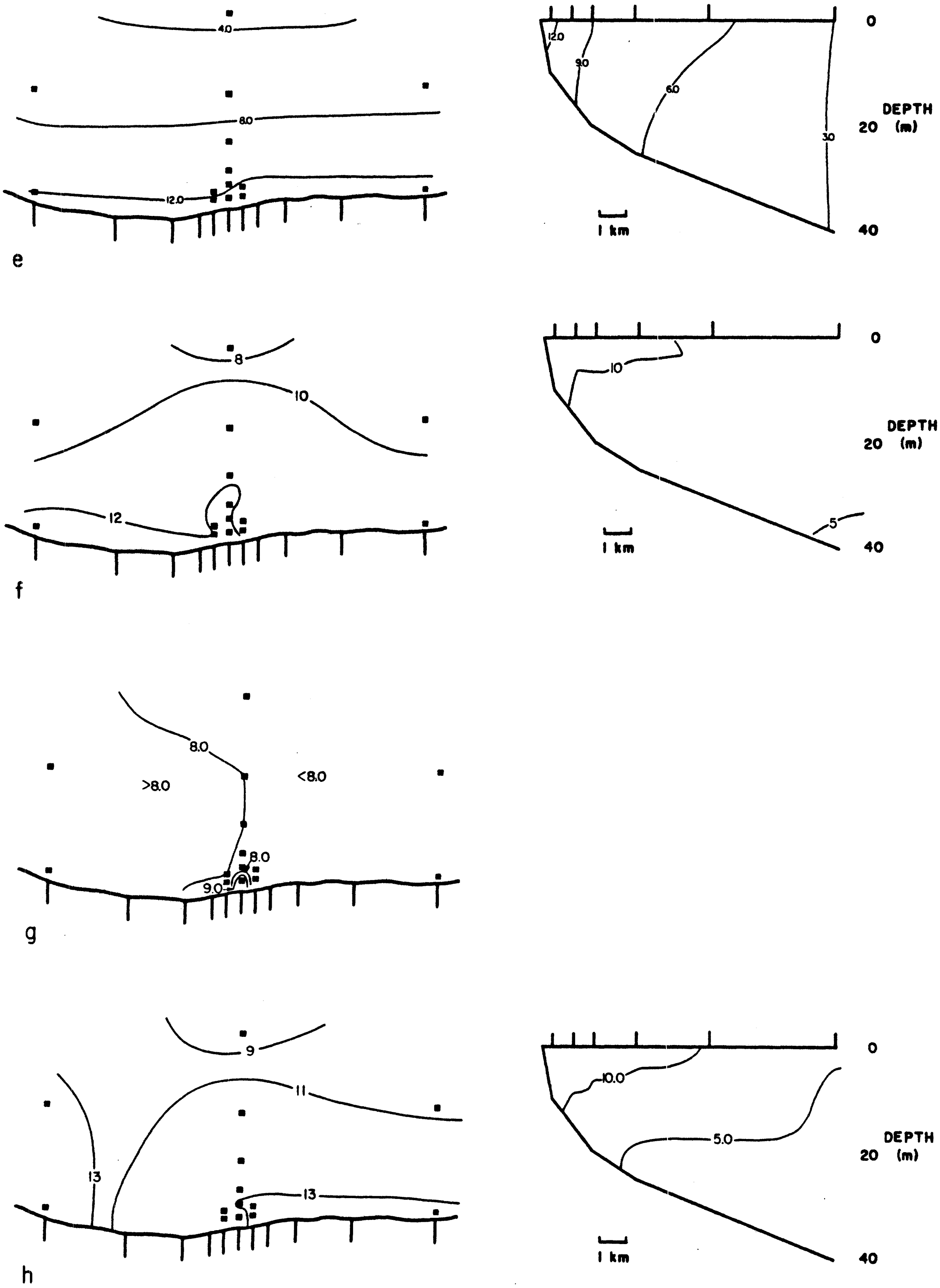


Fig. 2. Continued. e) 9 May 1979, f) 14 May 1980, g) 14 May 1981, h) 12 May 1982,

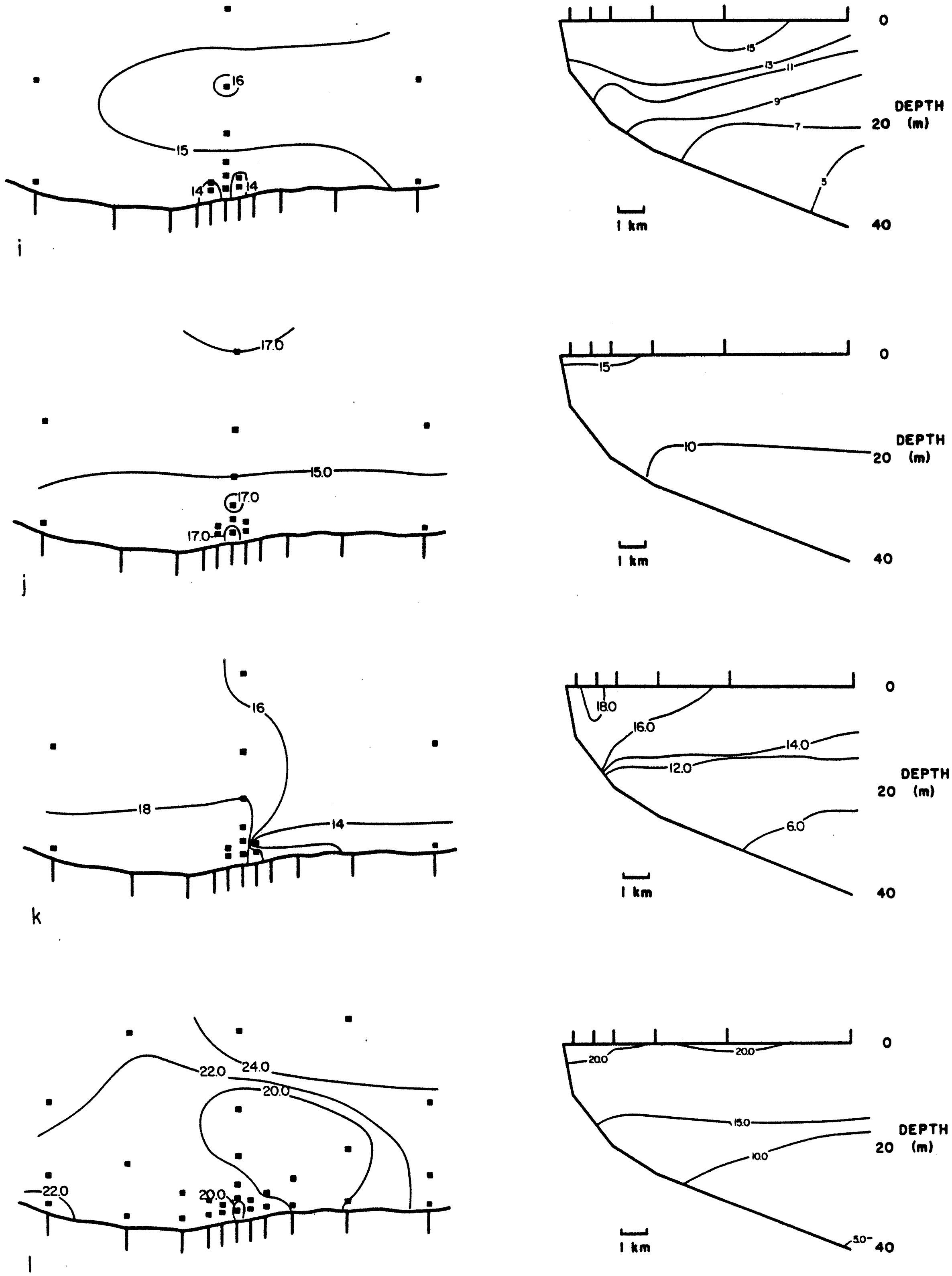


Fig. 2. Continued. i) 13 June 1979, j) 12 June 1980, k) 10 June 1981, l) 11 July 1979,

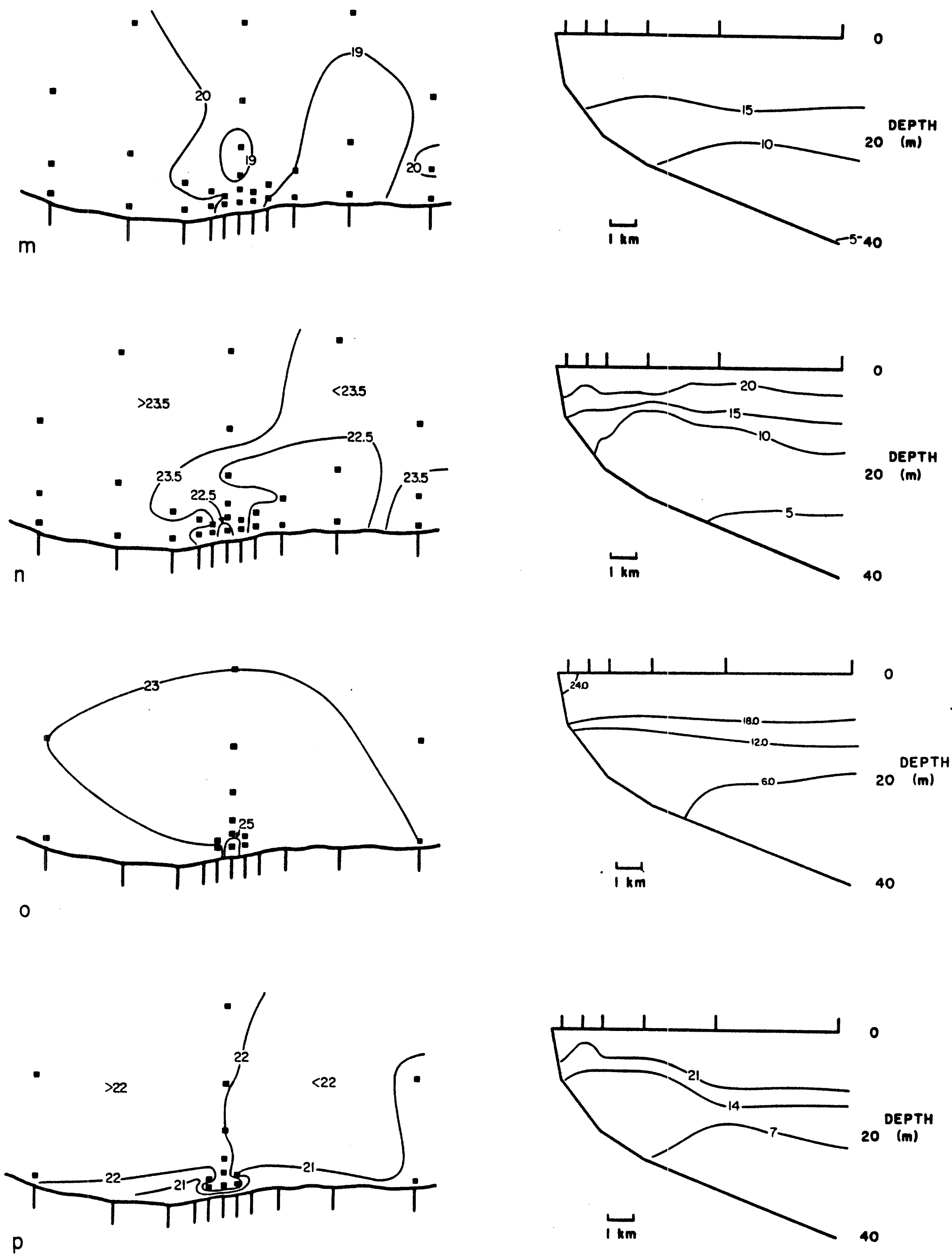


Fig. 2. Continued. m) 9 July 1980, n) 8 July 1981, o) 9 August 1979, p) 13 August 1980,

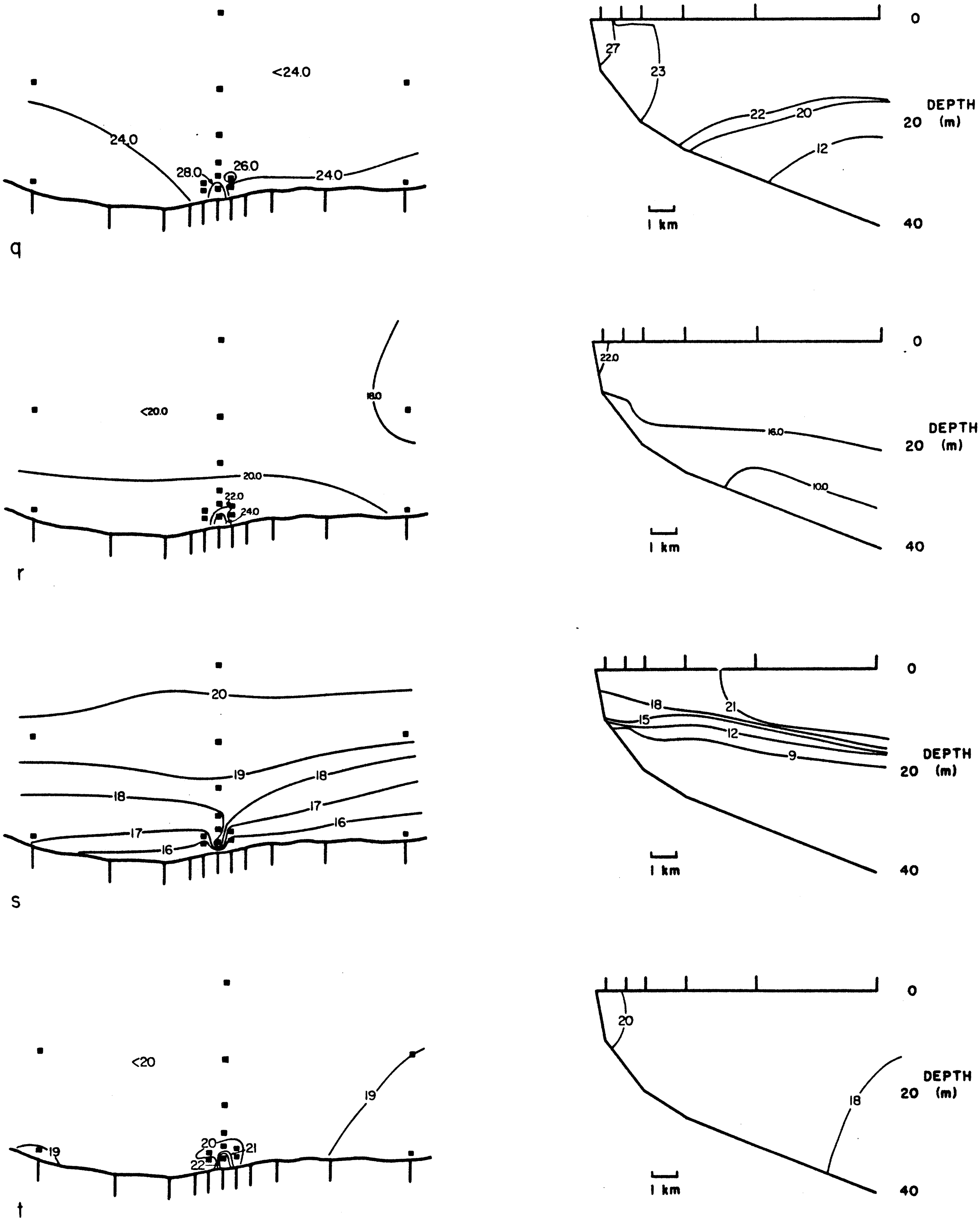


Fig. 2. Continued. q) 13 August 1981, r) 13 September 1979, s) 12 September 1980, t) 20 September 1981,

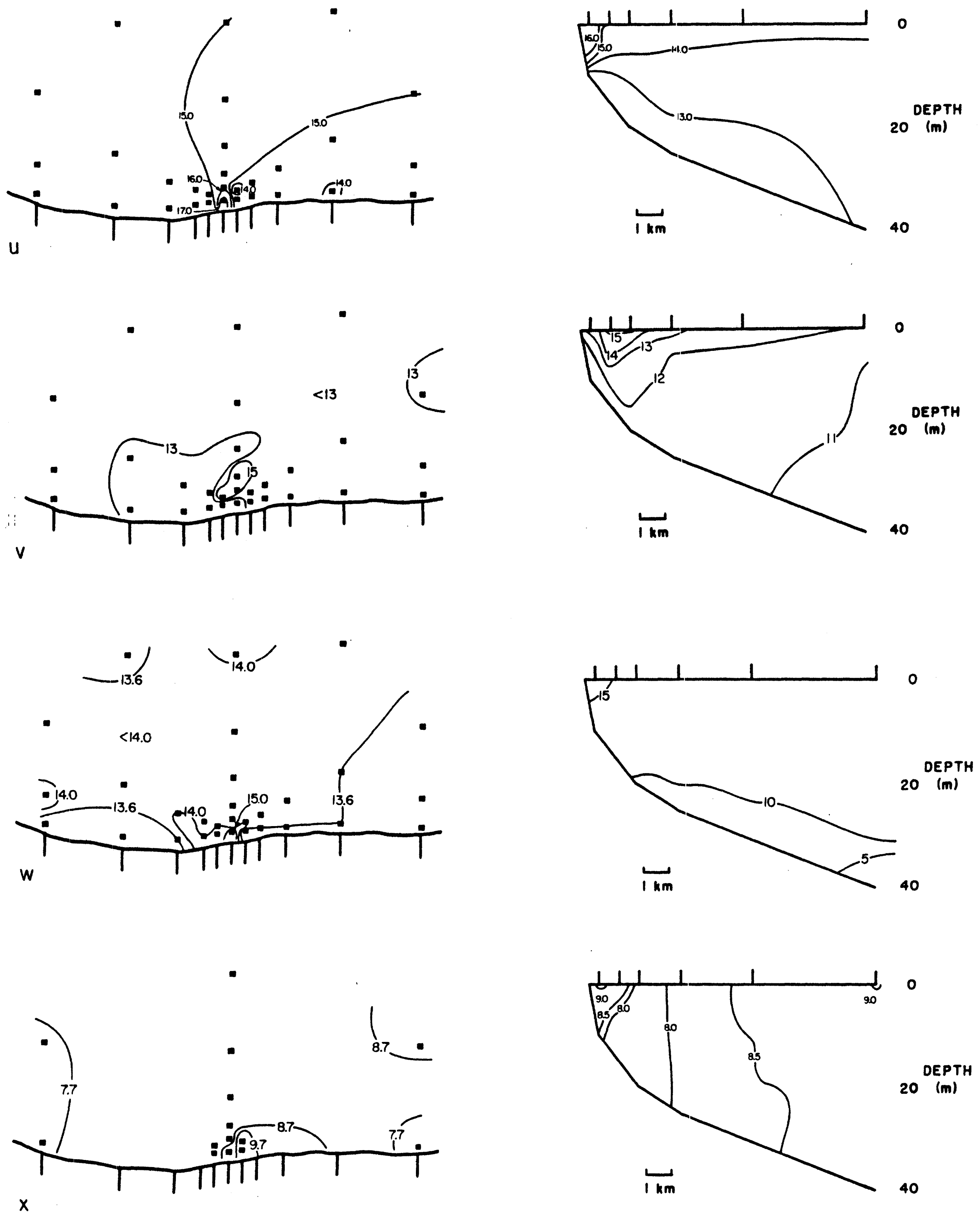
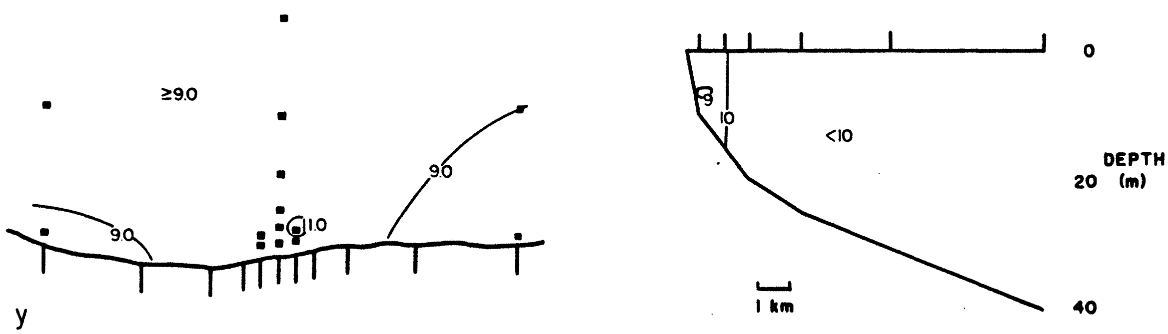


Fig. 2. Continued. u) 18 October 1979, v) 15 October 1980, w) 14 October 1981, x) 14 November 1979,



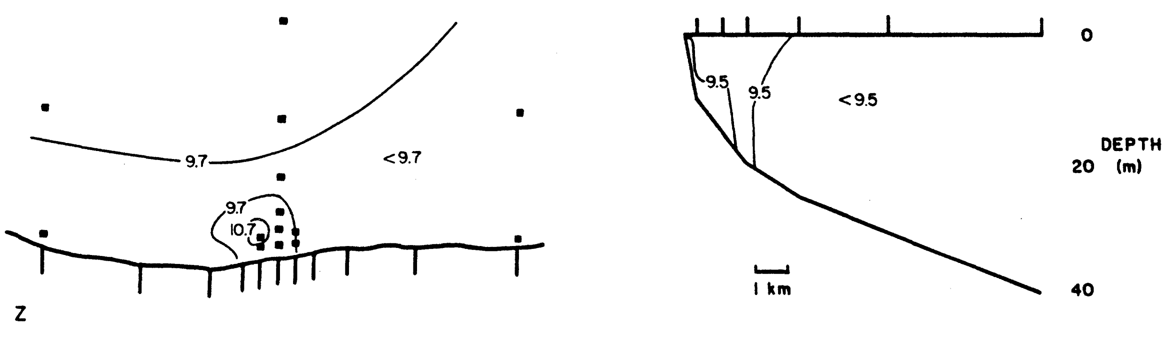


Fig. 2. Concluded. y) 12 November 1980, and z) 11 November 1981.

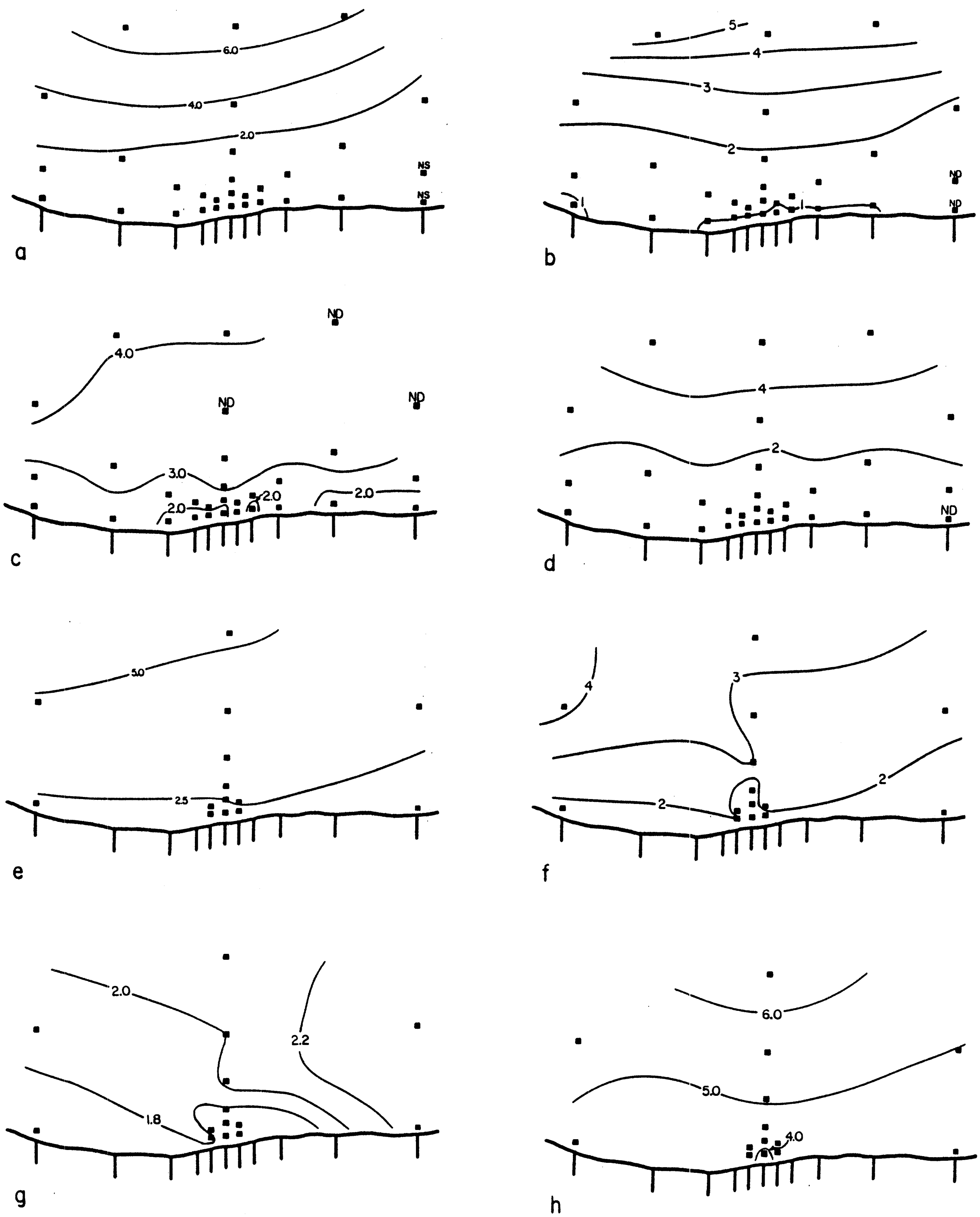


Fig. 3. Secchi disc depths in meters in a) 12 April 1979, b) 10 April 1980, c) 10 April 1981, d) 15 April 1982, e) 9 May 1979, f) 14 May 1980, g) 14 May 1981, h) 12 May 1982,

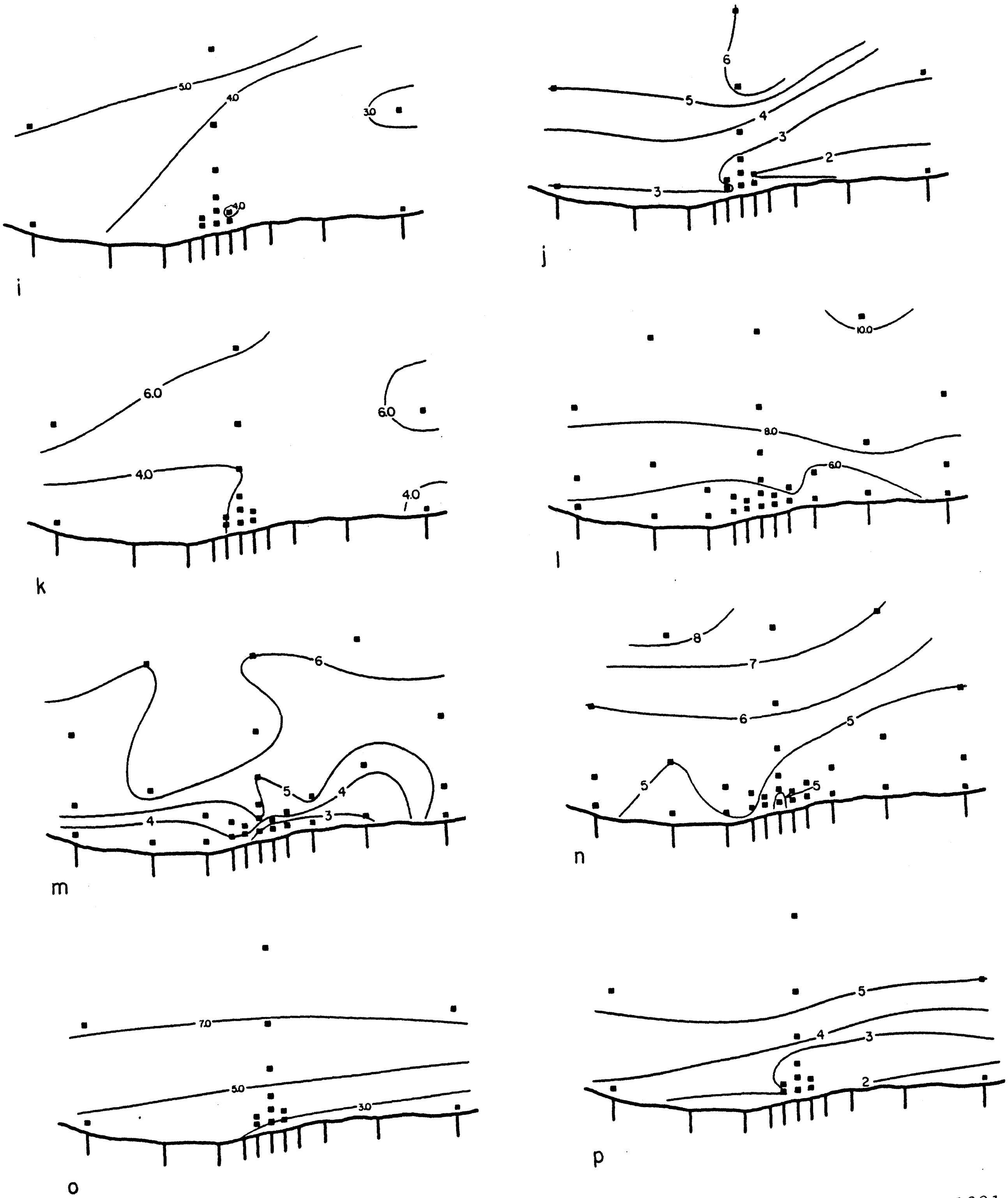


Fig. 3. Continued. i) 13 June 1979, j) 12 June 1980, k) 10 June 1981, l) 11 July 1979, m) 9 July 1980, n) 8 July 1981, o) 9 August 1979, p) 13 August 1980,

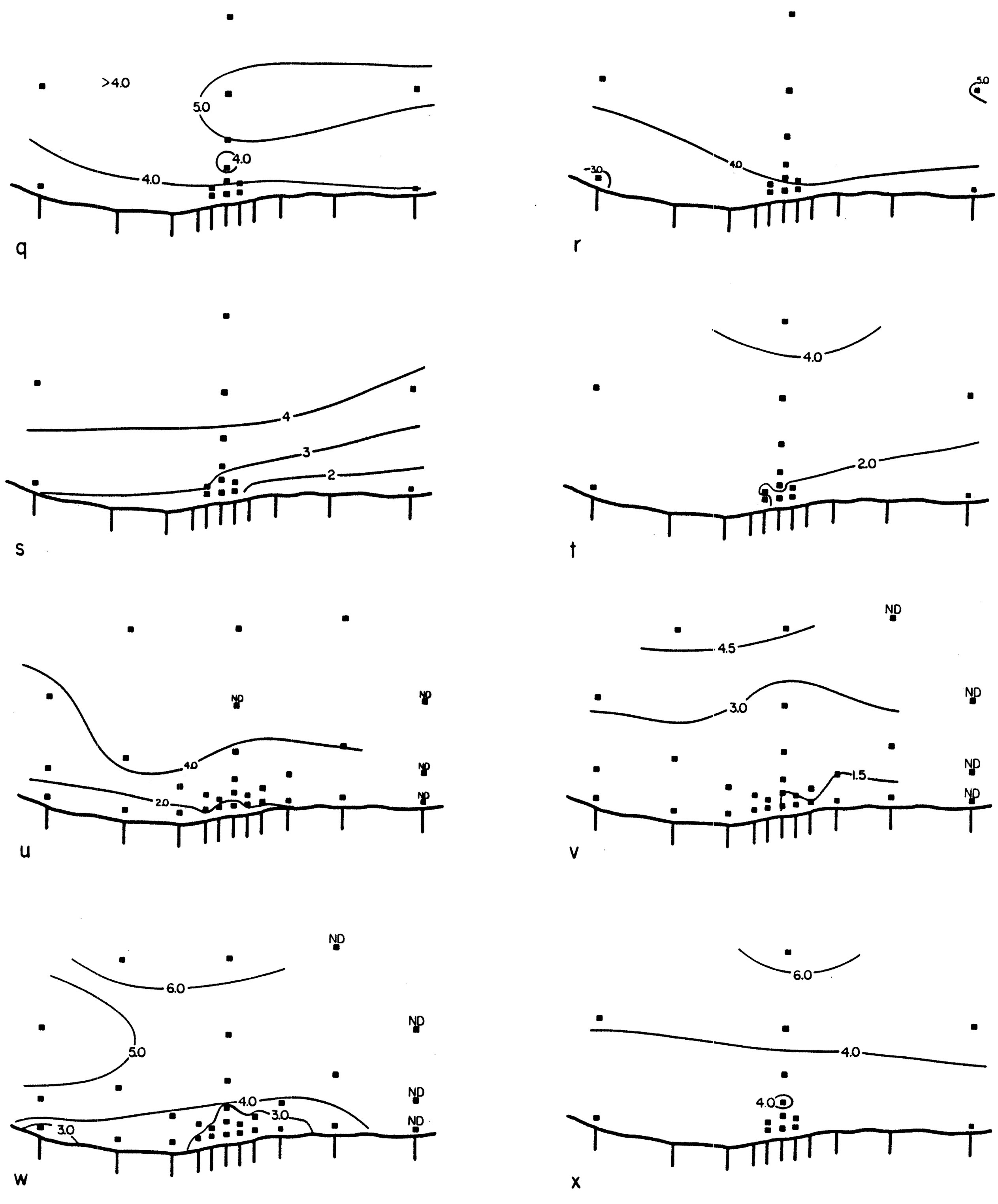
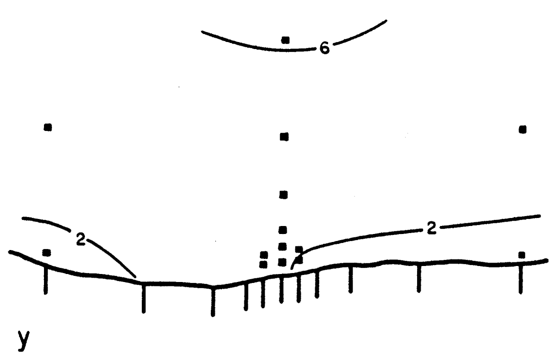


Fig. 3. Continued. q) 13 August 1981, r) 13 September 1979, s) 12 September 1980, t) 20 September 1981, u) 18 October 1979, v) 15 October 1980, w) 14 October 1981, x) 14 November 1979,



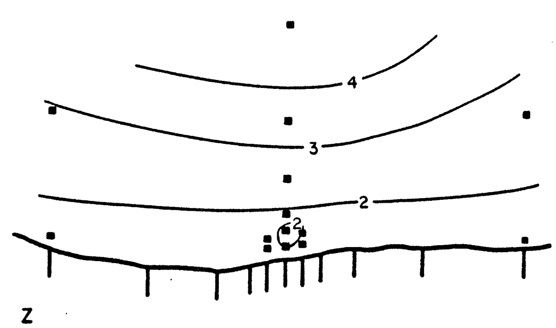


Fig. 3. Concluded. y) 12 November 1980, and z) 11 November 1981.

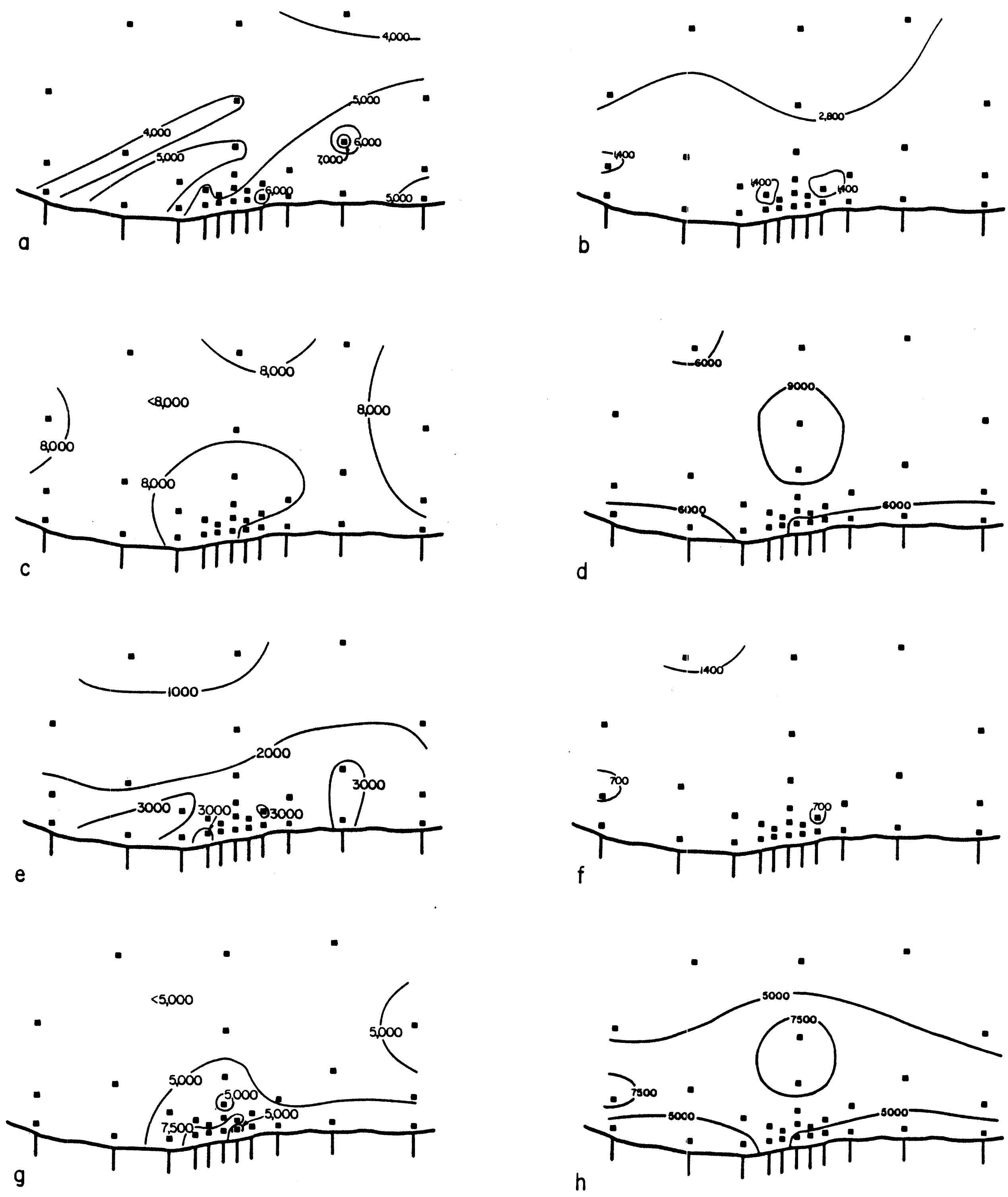


Fig. 4. Horizontal distributions (number/m^3) of total zooplankton and major zooplankton taxa collected on 12 April 1979, 10 April 1980, 10 April 1981, and 15 April 1982 respectively. a), b), c), and d) total zooplankton; e), f), g), and h) copepod nauplii,

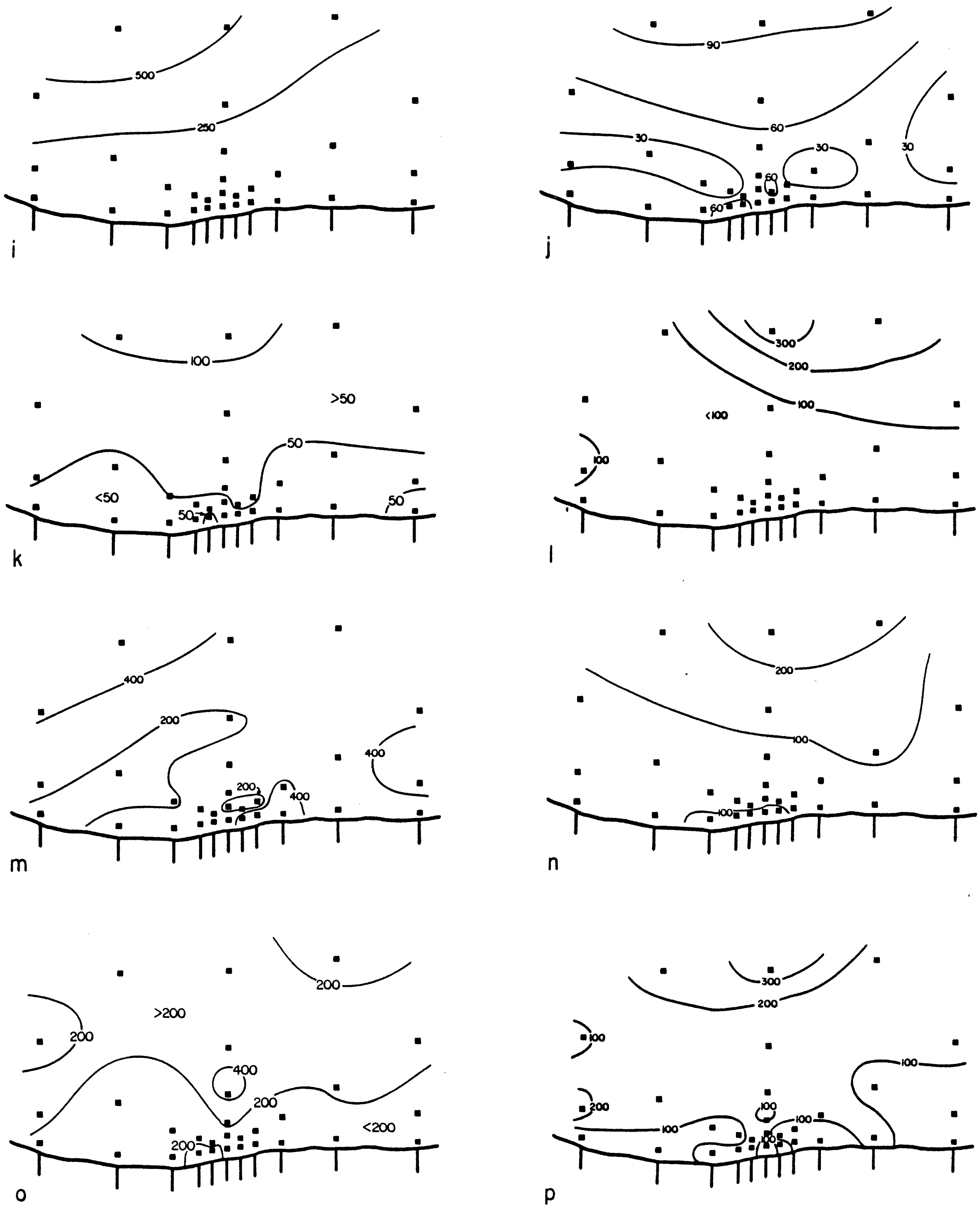


Fig. 4. Continued. i), j), k), and l) Cyclops spp. C1-C5, m), n), o), and p) Cyclops spp. C6,

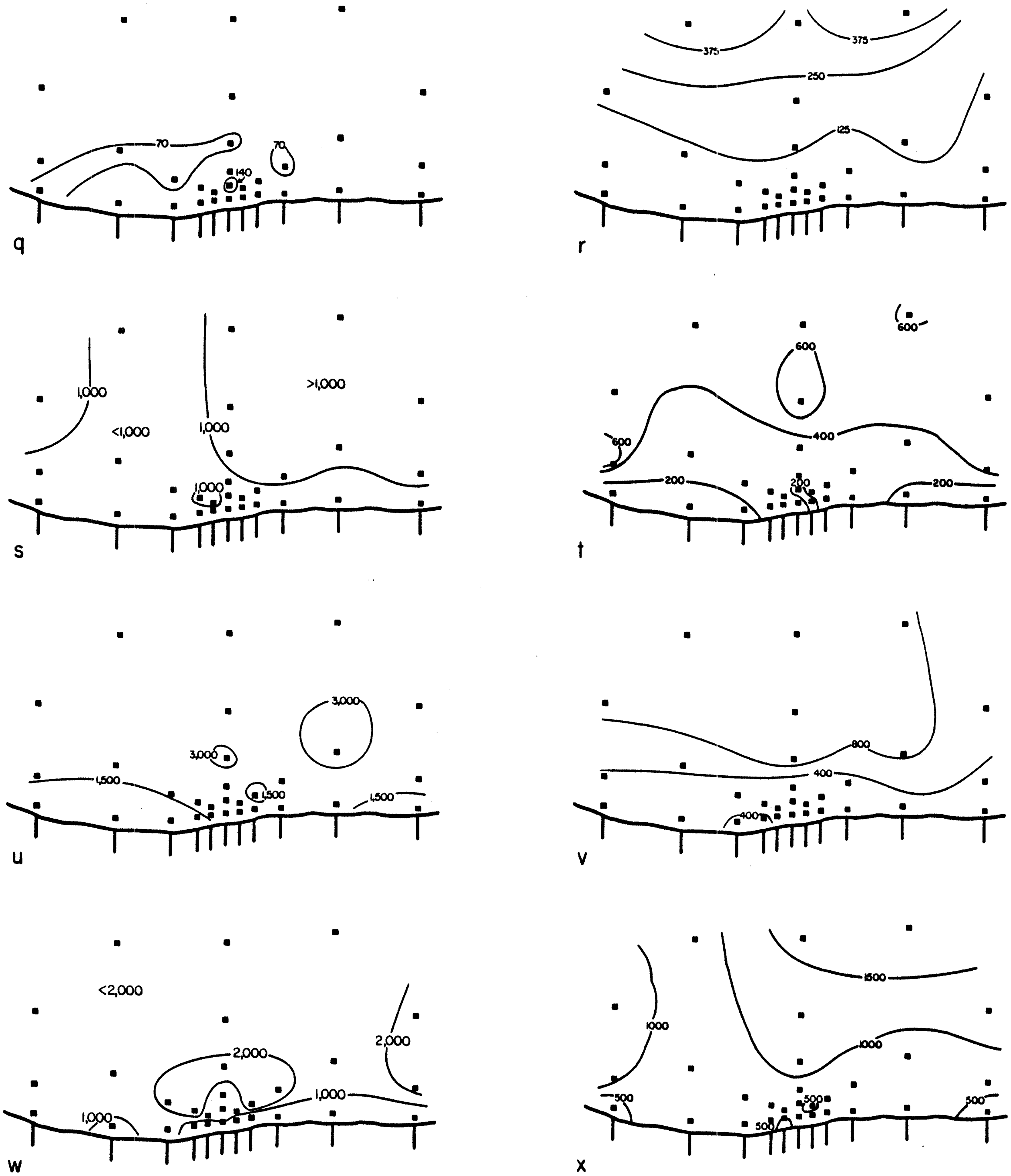


Fig. 4. Continued. q), r), s), and t) Diaptomus spp. C1-C5, u), v), w), and x) Diaptomus spp. C6,

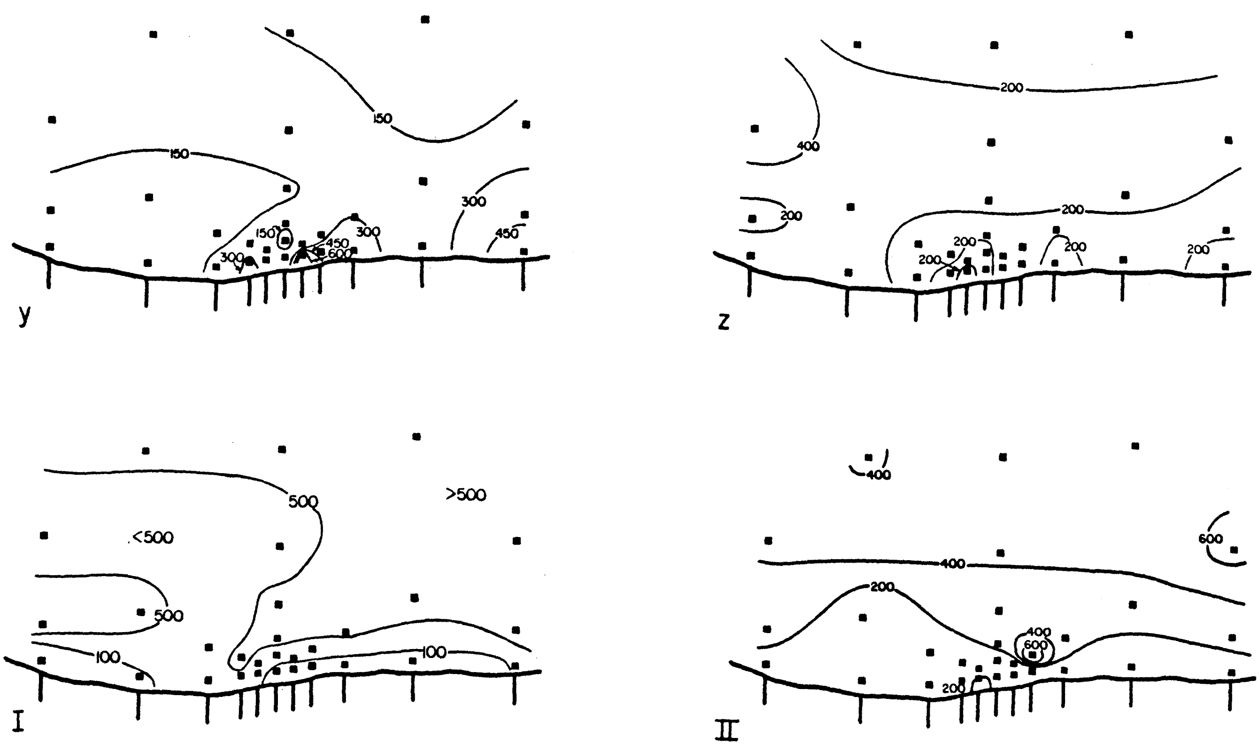


Fig. 4. Concluded. y), z), I), and II) *Limnocalanus macrurus* C1-C6.

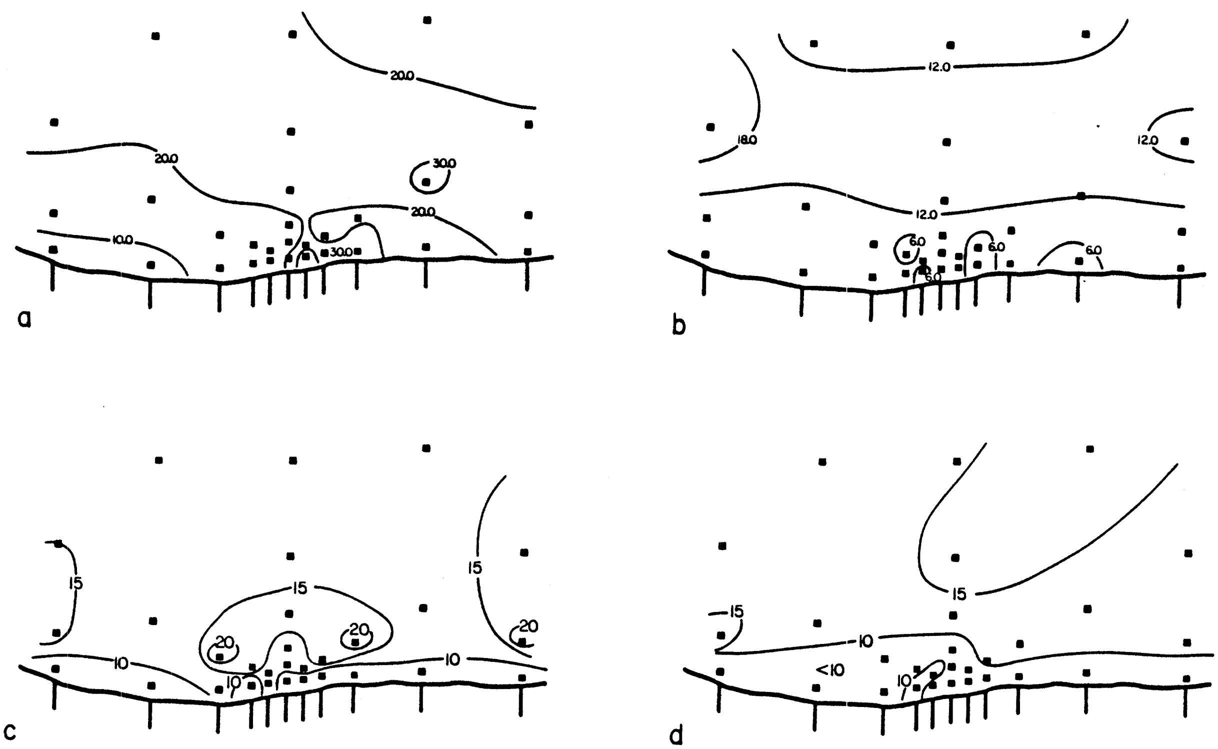


Fig. 5. The standing stock of zooplankton (mg dry weight/m^3) on a) 12 April 1979, b) 10 April 1980, c) 10 April 1981, and d) 15 April 1982.

10 April 1980

Surface-water temperatures were slightly higher than in April 1979, ranging from 1.5 to 10.1 °C (Fig. 2b). The thermal bar was 1 km from shore (Fig. 2b). High surface-water temperatures at DC-1, NDC-.5-1, and SDC-.5-1 indicated the presence of a small thermal plume flowing outward from the power plant in a northwest direction (Fig. 2b). Secchi disc depths ranged from 0.9 m to 5.8 m with lowest readings at stations closest to shore (Fig. 3b). Water color was murky green at shallow water stations, and bright- or dark-green in deeper waters.

Total zooplankton densities ranged from 1,160 to 3,190/m^3 (Fig. 4b). The zooplankton community was numerically dominated by copepod nauplii (Fig. 4f) which comprised 40 to 60% of the population over the survey area. Adult *Diaptomus* spp. (Fig. 4v) (primarily *D. ashlandi*) and *Limnocalanus macrurus* adults (Fig. 4z) were the next most common taxa. Immature *Diaptomus* were abundant at some offshore stations (Fig. 4r). Cladocerans (mainly *Chydorus sphaericus* and *Bosmina longirostris*) were present in small numbers at all inshore stations.

Unlike the April 1979 cruise, major taxa and total zooplankton abundances were generally higher in the offshore regions than in the inshore regions. Overall, zooplankton abundances were lower than April 1979. Copepod nauplii, adult *Diaptomus*, and immature *Cyclops* spp. copepodites showed the greatest differences in abundance while immature *Diaptomus* spp. copepodite concentrations were slightly higher than during the 1979 April cruise.

Biomass values ranged between 4.6 and 21.0 mg/m^3 (Fig. 5b). *Limnocalanus macrurus* and *Diaptomus ashlandi* accounted for most of the biomass over the

entire survey area while *D. sicilis* was a significant component of the offshore biomass.

10 April 1981

Surface-water temperatures ranged from 1.9 to 9.8 °C (Fig. 2c). Highest surface-water temperatures were recorded at inshore stations. The thermal plume was small and weakly defined (Fig. 2c). Temperatures, particularly in the inshore region, were somewhat higher than corresponding temperatures in April 1979 and 1980, indicating a warmer spring. The thermal bar also was farther offshore (4.5 km) than in the previous Aprils (Fig. 2c). Secchi disc depths ranged from 1.8 m to 4.2 m (Fig. 3c). Water color generally was murky- or gray-green.

Zooplankton abundance was higher than in previous April cruises. Densities ranged from 4,500 to 11,500/m^3 (Fig. 4c). Most of the high values occurred in the inshore and middle depth regions offshore of the plant. The generally higher zooplankton abundances during the April 1981 cruise may have been related to the relatively warm spring in 1981.

Copepod nauplii accounted for more than 50% of the zooplankton population by numbers (Fig. 4f). This percentage was greatest in the inshore region (70 to 80%). Immature *Diaptomus* spp. copepodites (Fig. 4s) and adult *D. ashlandi* (Fig. 4w) were abundant at all stations. In the offshore regions, *D. sicilis* (Fig. 4w) and *Limnocalanus macrurus* (Fig. 4I) also were numerous. As in previous Aprils, cladocerans were minor components of the zooplankton community with *Bosmina longirostris* and *Daphnia galeata mendotae* the most common taxa.

Despite the increased zooplankton abundance, biomass was about the same as in April 1980 (4.7 to 20.6 mg/m^3) (Fig. 5c). This was probably related to lower densities of the large *Limnocalanus macrurus* adults in the survey area than during the previous year. Copepod nauplii and *Diaptomus ashlandi* accounted for most of the biomass; *D. sicilis* was also a significant component in the offshore area.

15 April 1982

Lake warming was less intense in April 1982 than in April 1981 (Fig. 2d). Surface-water temperatures ranged from 1.2 to 10.2 °C. The thermal bar was located about 3.3 km offshore (Fig. 2d). Surface-water temperatures were somewhat higher in the immediate vicinity of the plant, indicating the presence of a small thermal plume flowing to the west (Fig. 2d). Secchi disc readings ranged from 1.0 m to 5.6 m (Fig. 3d). Lowest transparencies were found at inshore stations where water color was brownish olive-green. Secchi disc depths were highest at the deeper stations where water color was bluish- or gray-green.

Total zooplankton densities ranged from 3,890 to 11,200/m^3 (Fig. 4d) and were similar to those observed in April 1981. The major component of the zooplankton community was, as in the previous Aprils, copepod nauplii, which comprised an average of 77% of the population over the survey area (Fig. 4h). Adult *Diaptomus* spp. (primarily *D. ashlandi*) was the next most abundant taxon (Fig. 4x), with immature *Diaptomus* spp. copepodites (Fig. 4t) and *Limnocalanus macrurus* copepodites (Fig. 4 II) also abundant. Cladocerans were observed in low numbers over most of the survey area. This included a *Daphnia* species not frequently encountered in the past, *D. pulicaria*.

Biomass ranged from 5.1 to 17.5 mg/m^3 (Fig. 5d) and was mainly accounted for by copepod nauplii, and adult Diaptomus ashlandi and D. sicilis. Highest values were observed in the offshore region where the larger species (D. ashlandi and D. sicilis) were more numerous.

9 May 1979

Lake warming was well under way by the time of the May cruise, with surface-water temperatures markedly higher at most stations when compared with April 1979 values. Temperatures ranged from 3.5 to 14.1 °C (Fig. 2e). The thermal plume was small and weakly defined (Fig. 2e). The thermal bar was approximately 10 km offshore. The lake was not thermally stratified (Fig. 2e). Secchi surface transparencies ranged from 1.8 to 5.5 m (Fig. 3e) with the lowest readings occurring at shallower stations. Water was a murky green color over most of the survey area.

Total zooplankton abundance ranged from 4,100 to 22,000/m^3 (Fig. 6a). Highest zooplankton densities were observed in the inshore region, decreasing with distance from shore (Fig. 6a).

The zooplankton community was numerically dominated by copepod nauplii which accounted for 40 to 70% of the population. Immature Diaptomus spp. copepodites also were abundant over the survey area. In the middle depth zones, immature Limnocalanus macrurus copepodites were numerous, and in the offshore region, adult Diaptomus spp. (mainly D. sicilis and D. ashlandi) were abundant. Cladocerans were rare. Daphnia parvula, a small cladoceran first observed in May 1978, was found in low numbers (<5/m^3) at two stations.

Biomass ranged from 11.9 to 21.3 mg/m^3 (Fig. 7a). In the inshore region, copepod nauplii and immature Diaptomus spp. copepodites accounted for most of

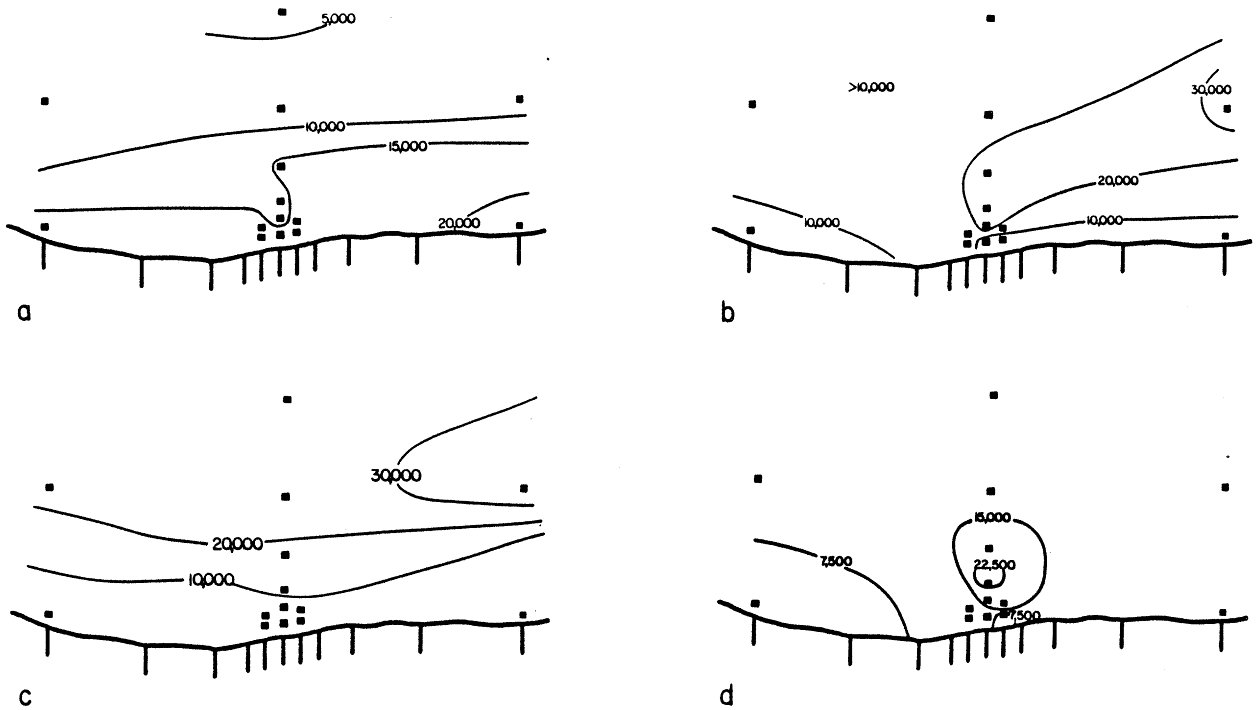


Fig. 6. The horizontal distribution (number/m^3) of total zooplankton collected on a) 9 May 1979, b) 14 May 1980, c) 14 May 1981, and d) 12 May 1982.

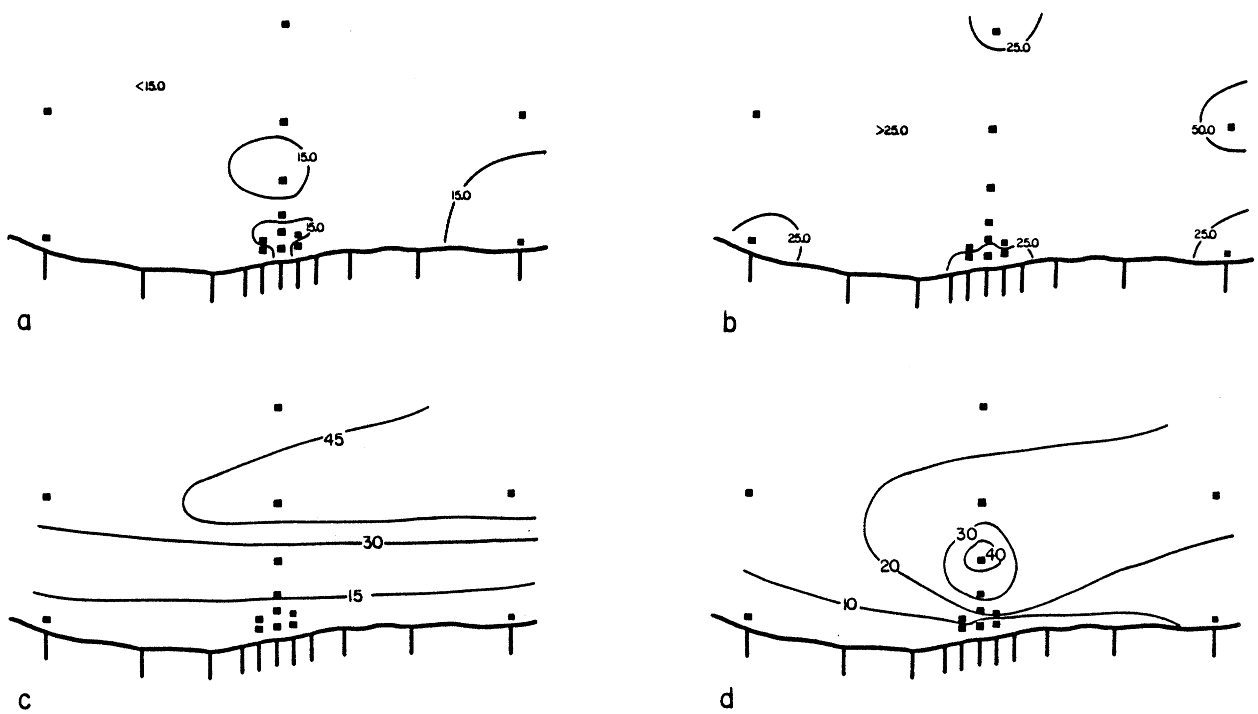


Fig. 7. The standing stock of zooplankton (mg dry weight/m^3) on a) 9 May 1979, b) 14 May 1980, c) 14 May 1981, and d) 12 May 1982.

the biomass while in the offshore areas, adult Diaptomus sicilis and D. ashlandi were large components of total biomass.

14 May 1980

Surface-water temperatures increased markedly from the previous month, as lake warming continued. Surface-water temperatures ranged from 7.8 to 13.5 °C and the beginning of thermal stratification was evident (Fig. 2f). The thermal plume was weakly defined. Secchi disc depths (Fig. 3f) ranged from 1.1 m to 4.9 m. The predominant water color was murky green.

Total zooplankton concentrations ranged from 1,400 to 31,200/m^3 (Fig. 6b) with lowest abundances occurring close to shore. Zooplankton were more abundant in May 1980 than in May 1979, primarily due to increased numbers of immature Diaptomus spp. copepodites, especially in the offshore region. Higher abundances may have been related to a relatively warmer spring in 1980 than in 1979.

Copepod nauplii and immature Diaptomus spp. copepodites were the dominant members of the zooplankton, composing 70 to 90% of the community by numbers. Other abundant taxa were immature Cyclops spp. and Limnocalanus macrurus copepodites. Cladocerans, (mainly Daphnia galeata mendotae and Bosmina longirostris) generally comprised a small percentage of the zooplankton at each station.

Biomass ranged from 1.3 to 59.1 mg/m^3 (Fig. 7b) with lowest values occurring in the inshore region. Immature Diaptomus spp. copepodites were the major component of the biomass at most stations followed by copepod nauplii, and immature Limnocalanus macrurus and Cyclops spp. copepodites.

14 May 1981

There was little variation in surface-water temperatures over the survey area with values ranging from 7.5 to 9.6 °C (Fig. 2g). Water temperatures were much lower than those observed in May 1980. Inshore water temperatures were similar to those recorded in April 1981 while offshore temperatures were much higher. The thermal plume covered a very small area around DC-1 and was weakly defined (Fig. 2g). No temperature-depth profile was taken due to an equipment malfunction. Secchi disc depths (Fig. 3g) ranged from 1.6 m to 2.6 m. Water color was gray-green.

Zooplankton densities ranged from 2,900 to 31,400/m^3 (Fig. 6c). Concentrations, which were similar to those observed in May 1980, were highest offshore. The numerically dominant taxa in the inshore region were copepod nauplii and the cladoceran, Bosmina longirostris, with immature Diaptomus spp. copepodites of secondary abundance. In the offshore region, immature Diaptomus spp. copepodites were dominant with copepod nauplii secondary in abundance. Immature Cyclops spp. and Limnocalanus macrurus copepodites also were abundant offshore. Adult Diaptomus spp. were not abundant.

Biomass ranged from 3.9 to 57.3 mg/m^3 (Fig. 7c) and was highest offshore. Nauplii and Bosmina longirostris accounted for most of the inshore region biomass. Immature Diaptomus spp. and Limnocalanus macrurus copepodites comprised most of the offshore region biomass. Adult Diaptomus spp., though not abundant, were also a significant component of offshore biomass.

12 May 1982

Surface-water temperatures ranged from 7.9 to 13.3 °C (Fig. 2h). Water temperatures decreased with distance offshore, and the thermal plume was

weakly defined (Fig. 2h). There was a strong warming trend throughout the survey area with lake temperatures much higher than a month earlier. Surface-water temperatures also were higher than corresponding values in May 1981. Thermal stratification was beginning to occur by mid-May 1982 (Fig. 2h). Secchi disc depths (Fig. 3h) ranged from 3.9 m to 6.3 m. Water color generally was gray-green.

Total zooplankton abundances ranged from 2,355 to 25,312/m^3 (Fig. 6d). Highest concentrations were observed in the middle depth zone and were associated with large numbers of nauplii at those stations.

Copepod nauplii was the major component (50 to 80%) of the zooplankton over the survey area, followed by immature Diaptomus spp. copepodites. Bosmina longirostris also were abundant in the inshore region while immature Limnocalanus macrurus copepodites were common in the offshore region. As in April 1982, low concentrations of Daphnia pulicaria were recorded.

Biomass ranged from 2.2 to 40.7 mg/m^3 (Fig. 7d). As in previous years, lowest values were recorded close to shore where copepod nauplii accounted for most of the biomass followed by immature Diaptomus spp. copepodites. Further offshore, immature Limnocalanus macrurus copepodites comprised the major fraction of the biomass. Copepod nauplii and Diaptomus spp. copepodites also were significant components of offshore region biomass.

13 June 1979

Surface-water temperatures (Fig. 2i) ranged from 13.2 to 15.7 °C. The thermal plume was small and weakly defined (Fig. 2i), and the lake was thermally stratified (Fig. 2i). Water temperatures, especially beyond the 10-m depth contour, were considerably higher than during the previous May

cruises. Secchi disc readings (Fig. 3i) ranged from 2.8 m to 5.8 m. Water color was dark green over the whole survey area.

Total zooplankton concentrations ranged from 10,700 to 49,000/m^3 (Fig. 8a) with highest values occurring in the middle depth region. High values were associated with large concentrations of immature *Diaptomus* spp. copepodites.

Bosmina longirostris and immature *Cyclops* spp. copepodites numerically dominated the inshore zooplankton population. Immature *Diaptomus* spp. copepodites, copepod nauplii, and the rotifer *Asplanchna* spp. also were numerous in the inshore region. In the middle and offshore regions, immature *Diaptomus* and *Cyclops* spp. copepodites were the most abundant taxa; copepod nauplii and *Bosmina longirostris* also were common.

Biomass followed a pattern similar to total zooplankton abundance, with highest values in the middle and offshore depth zones (Fig. 9a). Biomass ranged from 10.7 to 68.4 mg/m^3. Immature *Diaptomus* spp. copepodites accounted for the major portion of the biomass in the middle and offshore regions, followed by immature *Cyclops* spp. copepodites. In the inshore region, *Bosmina longirostris*, and immature *Cyclops* spp. and *Diaptomus* spp. copepodites were the major components of biomass.

12 June 1980

Surface-water temperatures ranged from 14.0 to 17.5 °C (Fig. 2j). Higher water temperatures were usually found at stations close to shore. The thermal plume was small and weakly defined (Fig. 2j). Thermal stratification was weak (Fig. 2j). Secchi disc depths (Fig. 3j) ranged from 1.5 m to 6.2 m. Highest

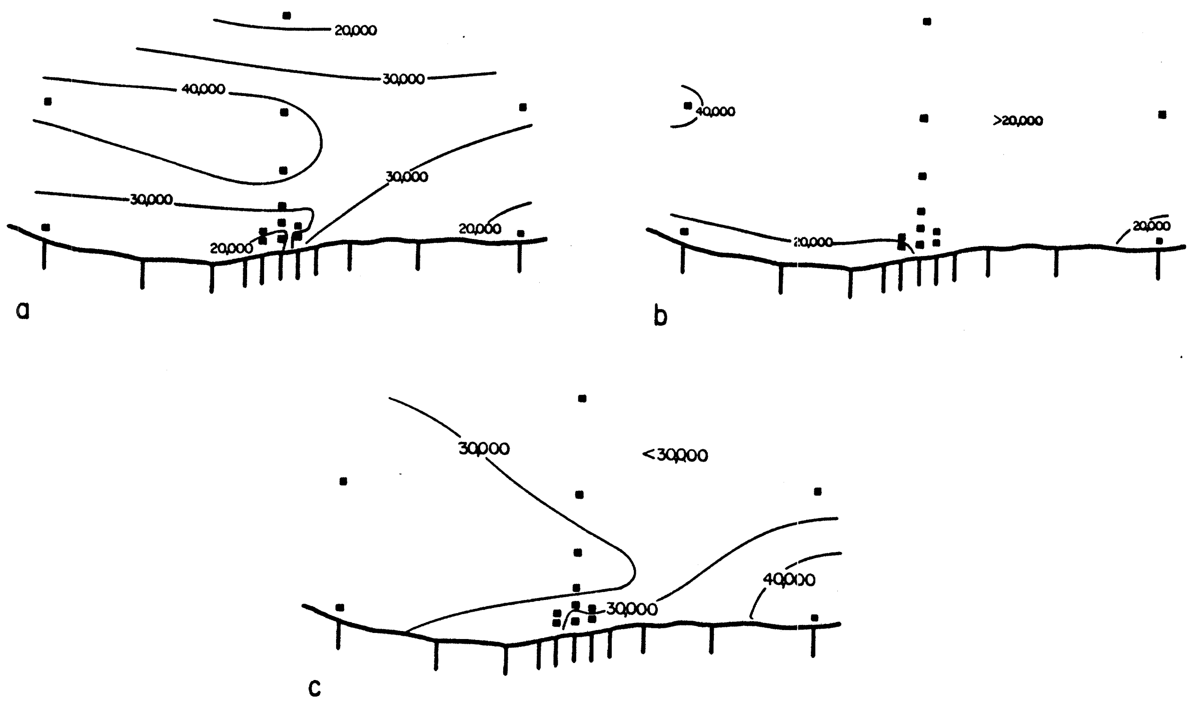


Fig. 8. The horizontal distribution of total zooplankton collected on a) 13 June 1979, b) 12 June 1980, and c) 10 June 1981.

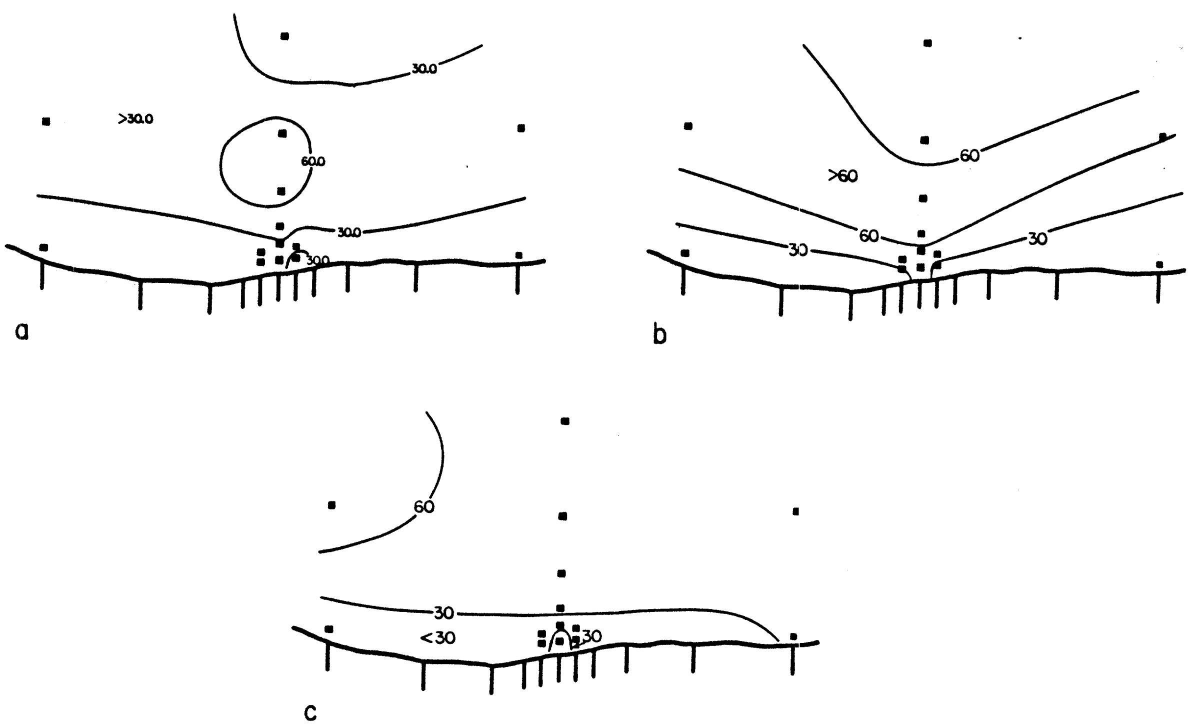


Fig. 9. The standing stock of zooplankton (mg dry weight/m^3) on a) 13 June 1979, b) 12 June 1980, and c) 10 June 1981.

values were recorded at the deepest stations where water color was blue-green. Water color over the rest of the survey area was murky-green.

Total zooplankton abundance ranged from 5,100 to 45,900/m^3 (Fig. 8b). Zooplankton densities were relatively uniform over the survey area (between 30,000 and 40,000/m^3), except at three stations close to shore where abundances were much lower (Fig. 8b).

The inshore zooplankton community was dominated by Bosmina longirostris, which comprised 60 to 80% of the inshore region population. Immature Cyclops spp. copepodites and Asplanchna spp. also were abundant in the inshore region. In the offshore region, immature Diaptomus and Cyclops spp. copepodites were the dominant taxa, followed by Bosmina longirostris and adult Cyclops bicuspidatus thomasi. Daphnia retrocurva were numerous at several stations throughout the survey area.

Biomass ranged from 4.9 to 84.9 mg/m^3 (Fig. 9b) with lowest values in the inshore region. The major component of the inshore biomass was Bosmina longirostris, while immature Diaptomus spp. copepodites were significant components of the offshore biomass. Cyclops spp. and Limnocalanus macrurus copepodites also were significant components of the offshore biomass.

10 June 1981

Surface-water temperatures were slightly higher in June 1980 than in June 1979 and 1980 with values ranging from 12.1 to 18.9 °C (Fig. 2k). The thermal plume was small and weakly defined (Fig. 2k). Thermal stratification was weak (Fig. 2k). Secchi disc depths (Fig. 3k) ranged from 2.8 to 6.8 m. Water color was murky-green to gray-green at stations with low transparency and turquoise at stations which had the highest water transparencies.

Zooplankton densities, which ranged from 21,200 to 43,300/m^3 (Fig. 8c), were higher in the inshore areas than in previous June cruises. Bosmina longirostris was the major taxon found in the inshore area, comprising about 80% of the zooplankton population at most stations. Most of the remainder of the inshore zooplankton community was composed of Asplanchna spp., immature Cyclops spp. and Diaptomus spp. copepodites, and copepod nauplii. Immature Diaptomus spp. copepodites was the numerically dominant offshore taxon (70%) with copepod nauplii, immature Cyclops spp. copepodites, adult Cyclops bicuspidatus thomasi, and adult Diaptomus spp. (mainly D. ashlandi) also common.

Biomass values were higher in the inshore zone in June 1981 than in June 1979 and 1980. Biomass ranged from 24.6 to 71.5 mg/m^3 (Fig. 9c). The inshore region biomass was composed primarily of Bosmina longirostris, while immature Diaptomus spp. copepodites accounted for most of the offshore biomass. In the middle depth zones, both Bosmina longirostris and immature Diaptomus spp. copepodites were significant components of biomass.

11 July 1979

Lake warming continued with surface-water temperatures ranging from 19.2 to 24.8 °C (Fig. 21). The thermal plume was small and weakly defined (Fig. 21). The lake was thermally stratified (Fig. 21). Secchi disc depths (Fig. 31) were relatively high throughout the survey area, ranging from 4.2 m to 10.7 m. Water transparency increased with distance offshore. Water color was blue-green at stations where Secchi readings exceeded 8.0 m. At other stations, the predominant color was murky green.

Total zooplankton ranged in density from 16,000 to 149,000/m^3 (Fig. 10a). Areas with highest densities corresponded with those areas with high Bosmina longirostris concentrations (Fig. 10v). This area was south of the plant.

The zooplankton community was numerically dominated by Bosmina longirostris over most of the survey area (Fig. 10v). Immature Cyclops spp. copepodites was the next most abundant taxon (Fig. 10g) while immature Diaptomus spp. copepodites (Fig. 10m) also were abundant, especially in the offshore areas. Copepod nauplii (Fig. 10d), Daphnia spp. (mainly D. retrocurva), and adult Cyclops bicuspidatus thomasi (Fig. 10j) were common in the inshore and middle depth regions.

Biomass, which ranged from 11.3 to 105.6 mg/m^3 (Fig. 11a), was primarily composed of Bosmina longirostris in the inshore region. Larger animals, including immature Cyclops spp. and Diaptomus spp. copepodites, and adult Cyclops bicuspidatus thomasi, accounted for most of the biomass in deeper regions.

9 July 1980

Surface-water temperatures in July 1980 increased by an average of 4.0 C° from the previous month but were lower than temperatures recorded in July 1979. Temperatures ranged from 18.2 to 20.9 °C (Fig. 2m). The thermal plume was small and weakly defined (Fig. 2m). The lake was thermally stratified (Fig. 2m). Secchi disc depths (Fig. 3m) ranged from 2.8 m to 7.0 m and increased with distance offshore. Water color was blue-green to green at most stations.

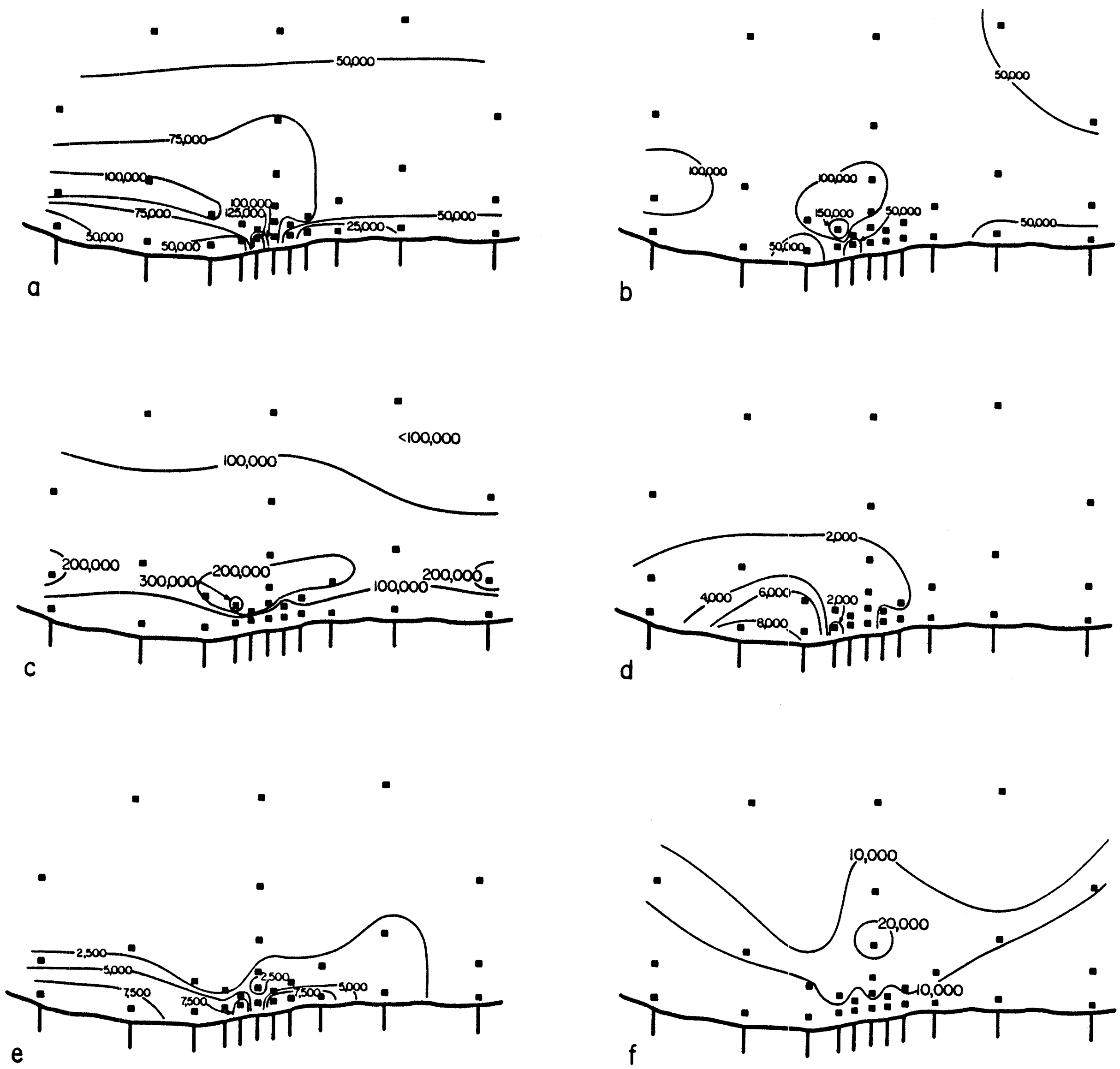


Fig. 10. Horizontal distributions (number/m^3) of total zooplankton and major taxa collected on 11 July 1979, 9 July 1980, and 8 July 1981 respectively. a), b), and c) total zooplankton, d), e), and f) copepod nauplii,

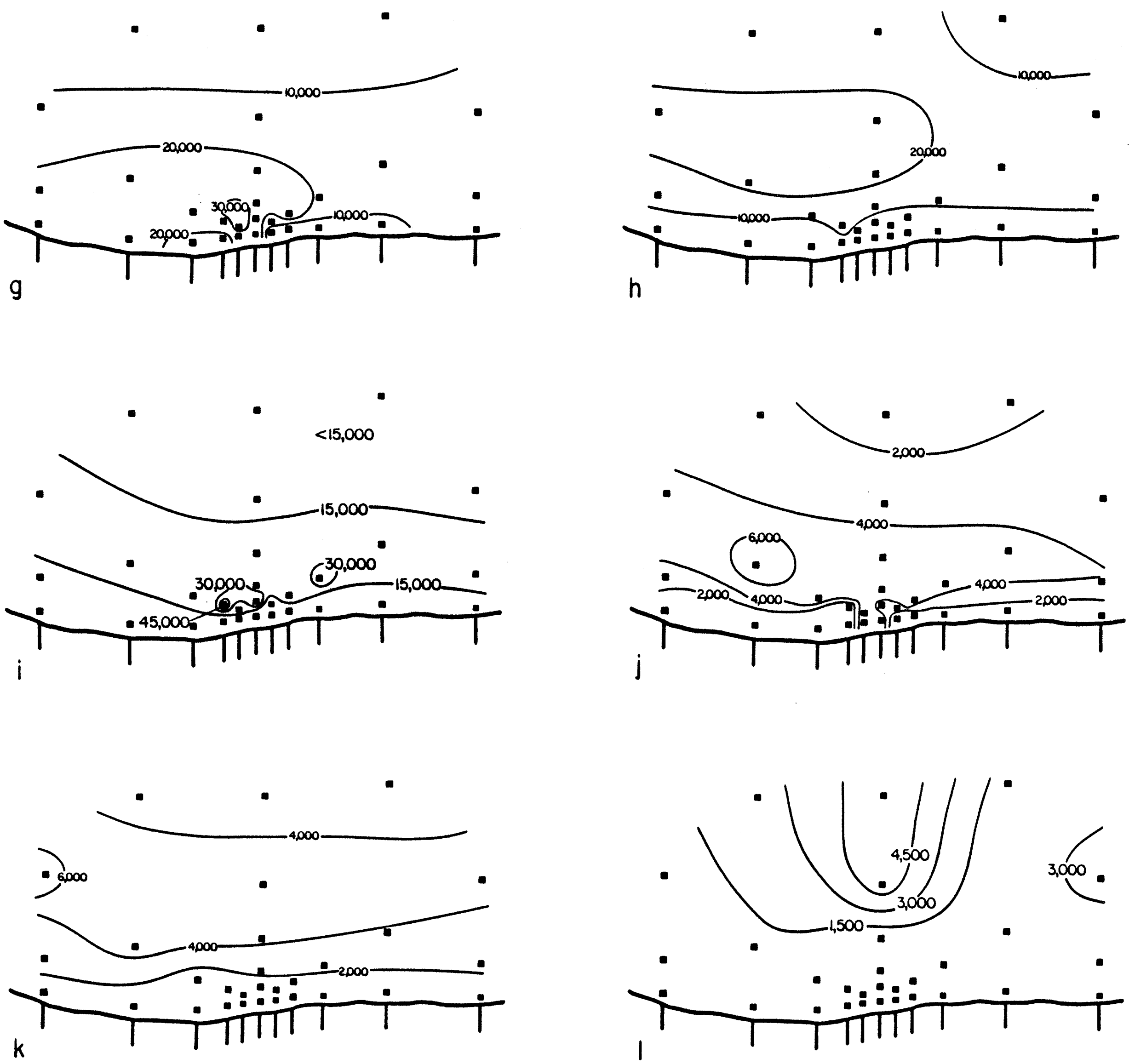


Fig. 10. Continued. g), h), and i) <u>Cyclops</u> spp. C1-C5, j), k), and l) <u>Cyclops</u> spp. C6,

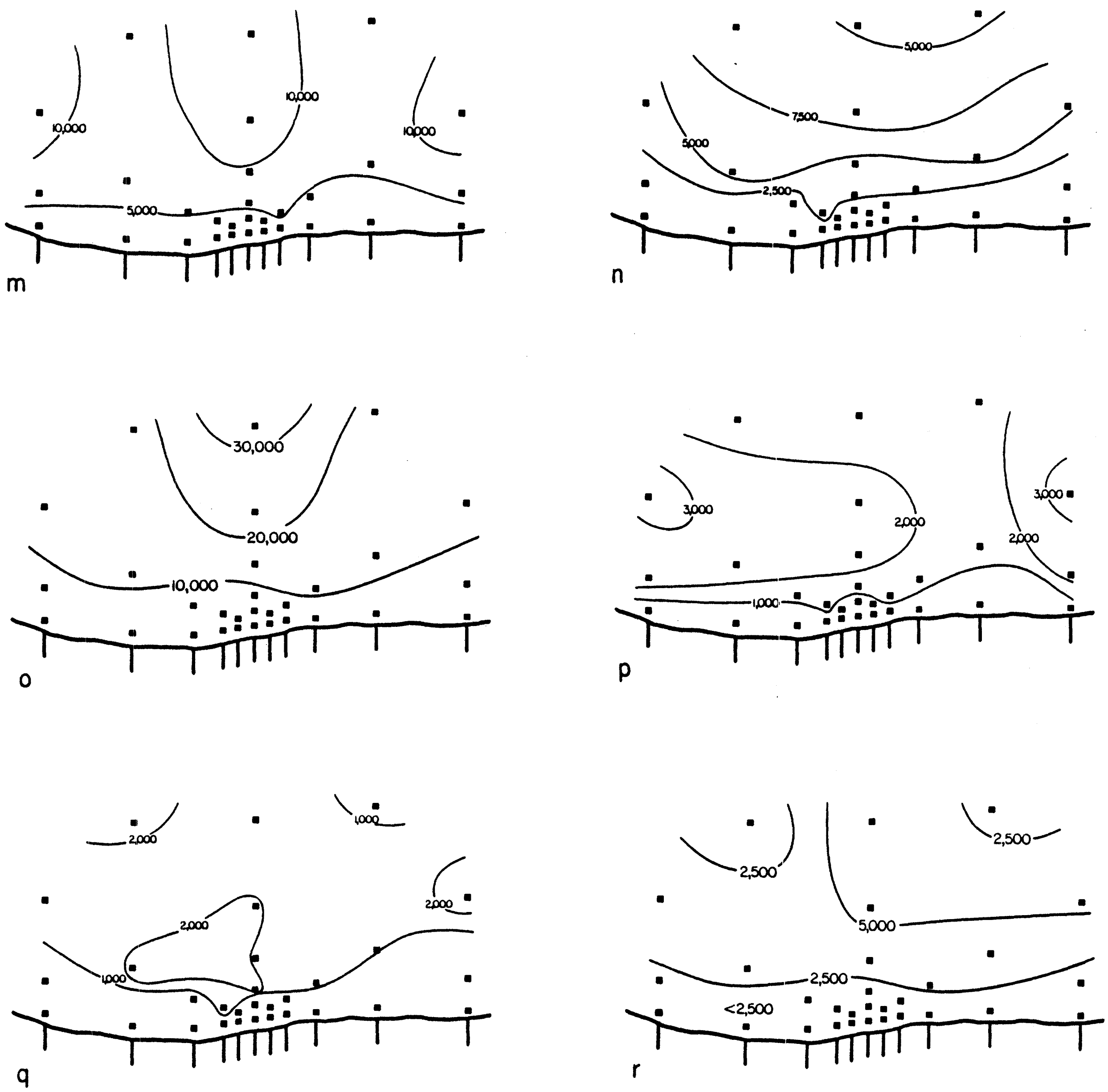


Fig. 10. Continued. m), n), and o) Diaptomus spp. C1-C5, p), q), and r) Diaptomus spp. C6,

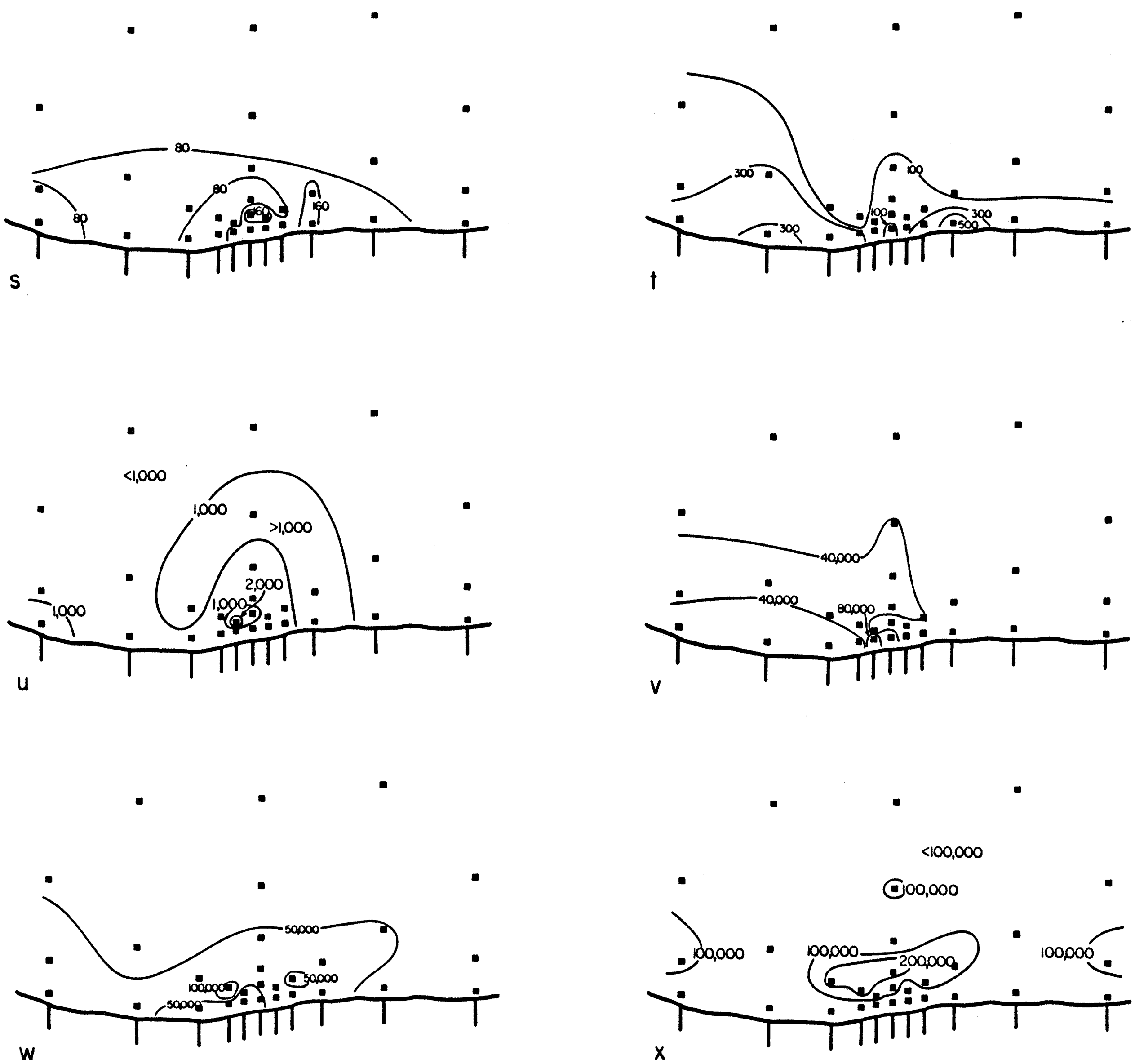


Fig. 10. Continued. s), t), and u) <u>Eurytemora affinis</u> C1-C6, v), w), and x) <u>Bosmina longirostris</u>,

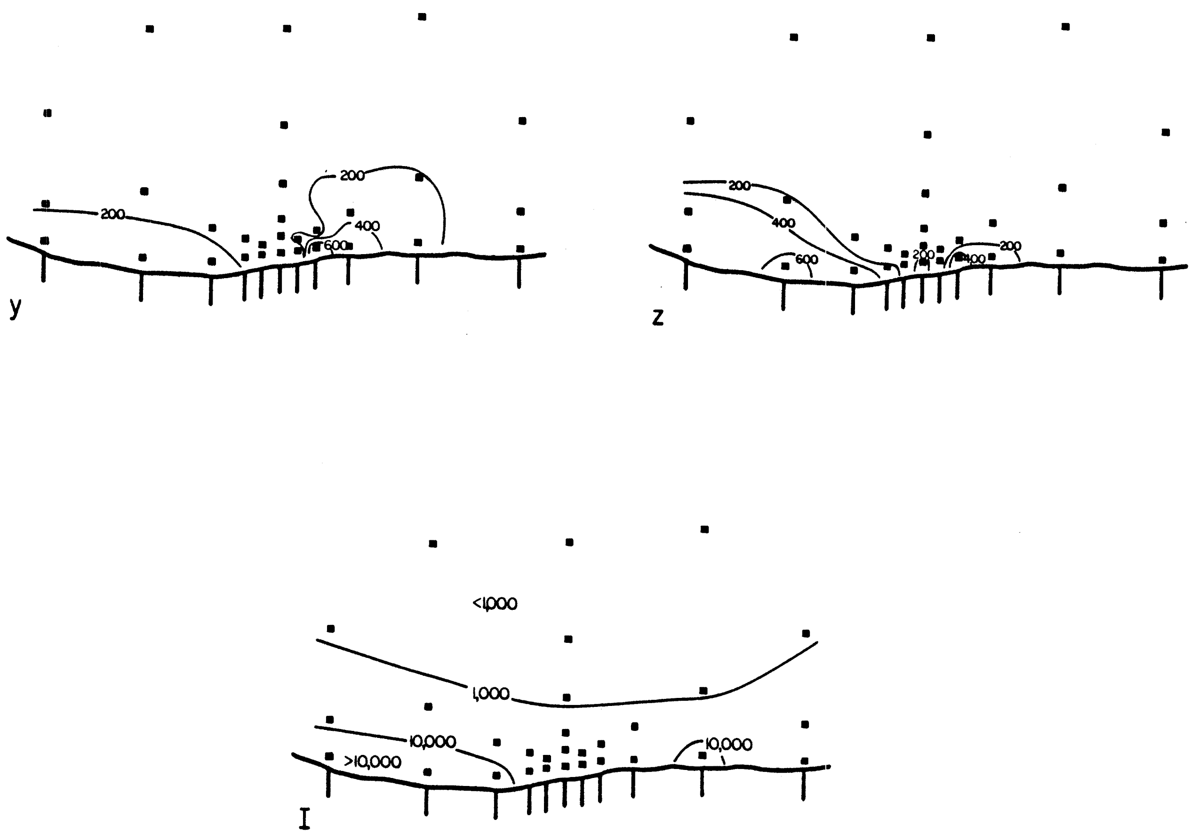


Fig. 10. Concluded. y), z), and I) Asplanchna spp.

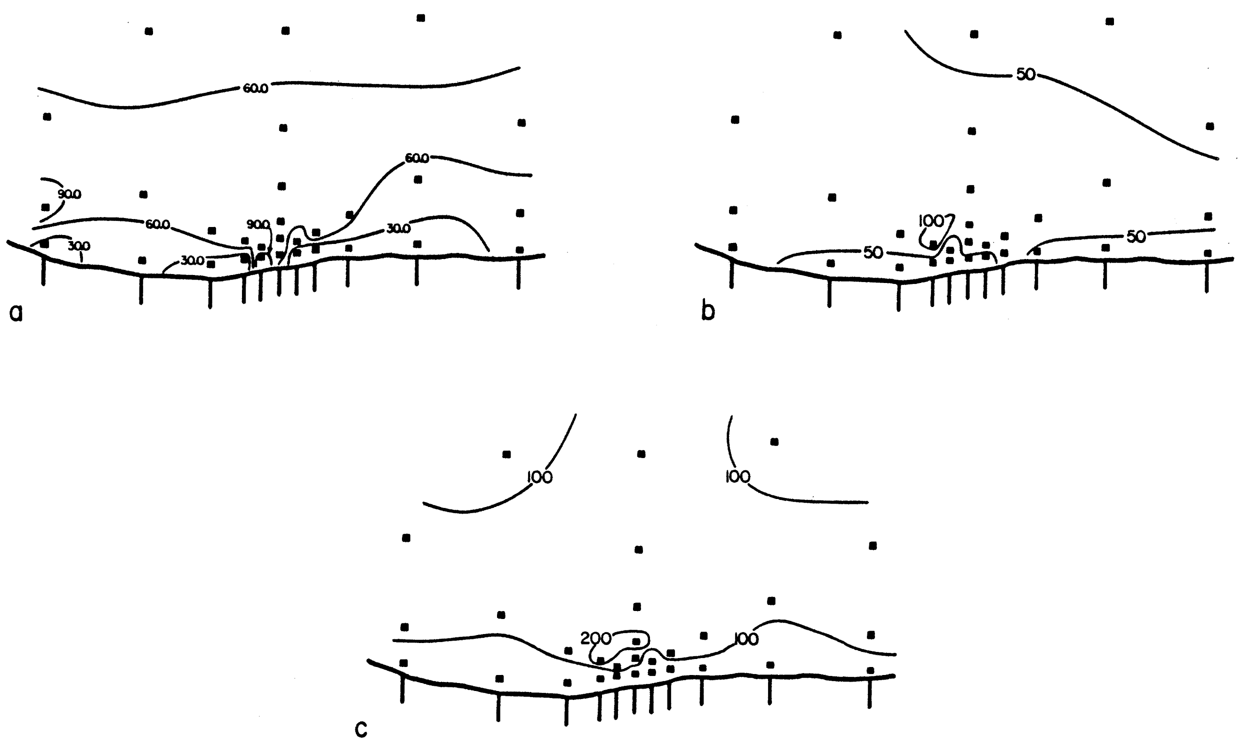


Fig. 11. The standing stock of zooplankton (mg dry weight/m^3) on a) 11 July 1979, b) 9 July 1980, and c) 8 July 1981.

Zooplankton densities ranged from 19,000 to 154,000/m^3 (Fig. 10b) and were similar to those observed in July 1979. Highest abundances were observed in the middle depth zone.

Bosmina longirostris was the major component of the zooplankton community (Fig. 10w), especially in the inshore region where it comprised 80% of the population. Also abundant in the inshore region were copepod nauplii (Fig. 10e) and immature *Cyclops* spp. copepodites (Fig. 10h). In the offshore region, *Bosmina longirostris* and immature *Cyclops* spp. copepodites were the taxa groups followed by immature *Diaptomus* spp. copepodites (Fig. 10n) and *Daphnia* spp. (primarily *D. retrocurva*).

Biomass, which ranged from 9.4 to 116.3 mg/m^3 (Fig. 11b), was generally greatest in the middle and inner offshore regions. *Bosmina longirostris* accounted for the largest fraction of the biomass at most stations although, in offshore regions, larger organisms (*Daphnia retrocurva*, and immature *Cyclops* spp. and *Diaptomus* spp. copepodites) also were significant components of biomass.

8 July 1981

Surface-water temperatures increased more than 5.0 C° from June 1981, ranging from 21.8 to 24.4 °C (Fig. 2n). Water temperatures were higher than during previous July cruises. The thermal plume was weakly defined (Fig. 2n). As in July 1980, surface-water temperatures in the northern part of the survey area were slightly lower than temperatures to the south. The lake was thermally stratified (Fig. 2m). Secchi disc transparencies ranged from 4.4 m to 8.0 m (Fig. 3n) and generally increased with distance from shore. Water

color was clear blue- or gray-green in the offshore region and murky grass- or pea-green in the inshore region.

Total zooplankton abundance ranged from 13,000 to 314,000/m^3 (Fig. 10c) and, in general, was higher than in previous years. Highest densities were observed in the middle depth region, following the pattern for Bosmina longirostris abundance (Fig. 10x).

In the inshore and middle depth regions, the dominant zooplankton taxon was Bosmina longirostris (Fig. 10x) except at several inshore stations where Asplanchna spp. dominated (Fig. 10I). Although Asplanchna spp. was not a dominant taxon in the past, it accounted for an average of 24% of the inshore region population and 79% at one station (SDC-4-1). Other taxa which were abundant in the inshore region were copepod nauplii (Fig. 10f) and immature Cyclops spp. copepodites (Fig. 10i). In the offshore region, Bosmina longirostris and immature Diaptomus spp. copepodites (Fig. 10o) were the major components of the zooplankton population followed by copepod nauplii and immature Cyclops spp. copepodites.

Biomass ranged from 7.2 to 201.2 mg/m^3 (Fig. 11c) with highest values in the middle depth zone. Bosmina longirostris comprised most of the biomass in the inshore and middle depth regions while immature Diaptomus spp. copepodites accounted for the largest fraction of the offshore region biomass: Bosmina longirostris accounted for the second largest fraction of the offshore zooplankton biomass.

9 August 1979

Surface-water temperatures in August averaged about 3.0 C° higher than in the previous month. Surface-water temperatures (Fig. 2o) ranged from 22.5 to

25.6 °C. The thermal plume was small and weakly defined (Fig. 2o). The lake was thermally stratified (Fig. 2o). Secchi disc depths, ranging from 1.9 m to 8.4 m, increased with distance offshore (Fig. 3o). Water color was blue-green in the offshore region and green in the inshore region.

Total zooplankton abundance ranged from 10,500 to 55,300/m^3 (Fig. 12a) with highest densities occurring in the middle depth region offshore of the plant. The inshore region zooplankton population was numerically dominated by Bosmina longirostris followed by copepod nauplii. Immature Cyclops spp. and Diaptomus spp. copepodites, and Daphnia spp. (primarily D. retrocurva) also were common inshore. Zooplankton in the offshore regions were mainly composed of immature Diaptomus spp. copepodites, with immature Cyclops spp. copepodites and Daphnia spp. also numerous.

Biomass ranged from 12.4 to 116.3 mg/m^3 (Fig. 13a). These values were similar to those observed during the previous month despite lower total abundance: it reflects an increase in the abundance of larger zooplankton, especially in the offshore region. In the inshore region, zooplankton biomass was dominated by Bosmina longirostris, immature Diaptomus spp. copepodites, and, at some stations, Daphnia retrocurva. In the offshore region, immature Diaptomus spp. copepodites and Daphnia galeata mendotae accounted for most of the biomass with adult Limnocalanus macrurus also a significant biomass component.

13 August 1980

Surface-water temperatures ranged from 20.8 to 23.0 °C (Fig. 2p). Surface-water temperatures were higher than temperatures observed in July 1980, but lower than corresponding values in August 1979. The thermal plume

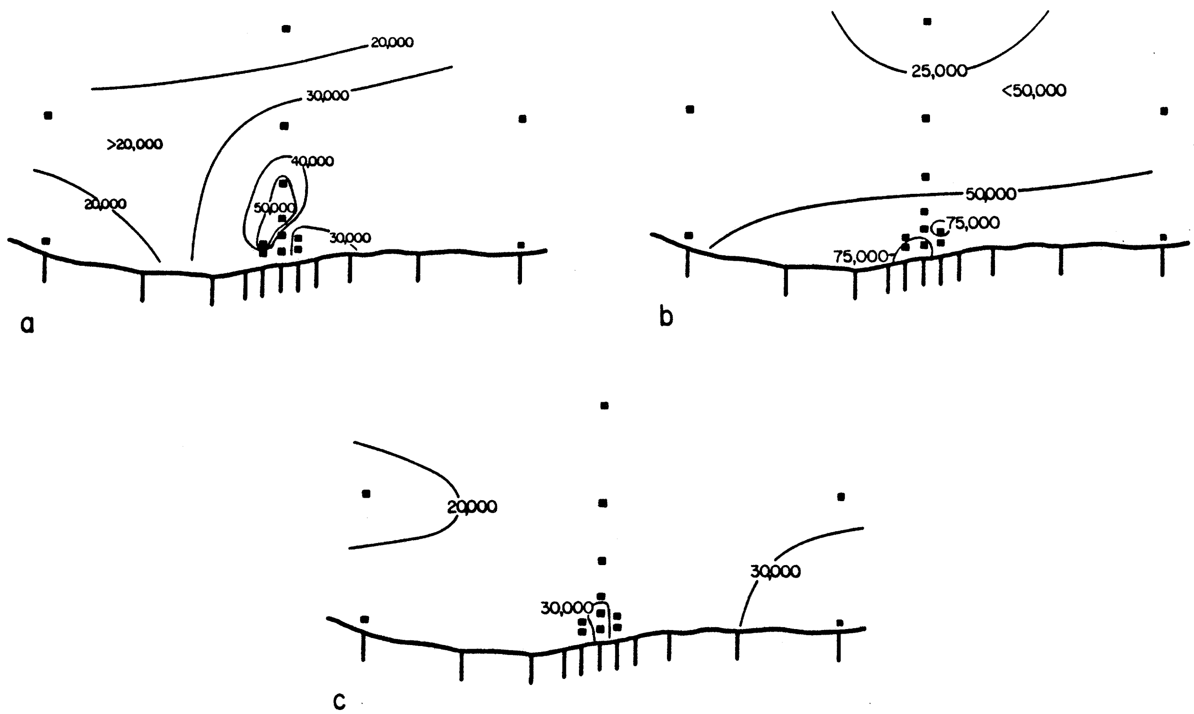


Fig. 12. The horizontal distribution of total zooplankton (number/m^3) collected on a) 9 August 1979, b) 13 August 1980, and c) 13 August 1981.

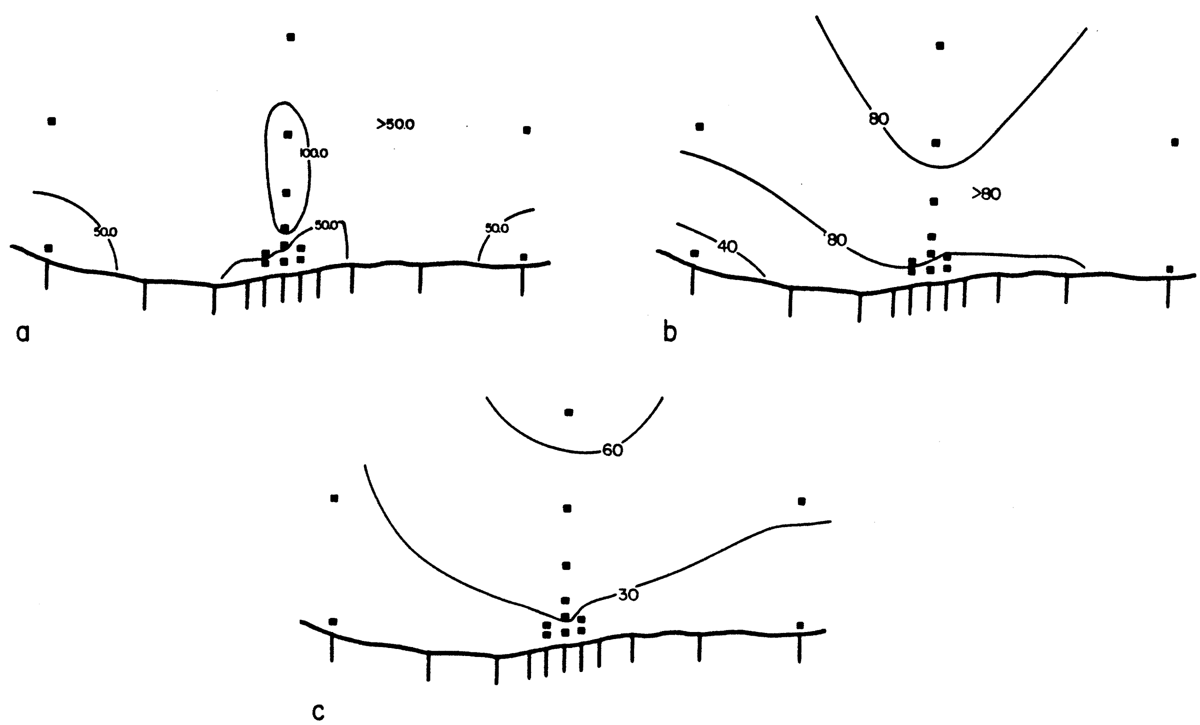


Fig. 13. The standing stock of zooplankton (mg dry weight/m^3) on a) 9 August 1979, b) 13 August 1980, and c) 13 August 1981.

was weakly defined (Fig. 2p). The lake was thermally stratified (Fig. 2p). Secchi disc transparencies (Fig. 3p) ranged from 1.9 m to 5.9 m. Water color was murky green over most of the survey area.

Total zooplankton abundance ranged from 20,700 to 95,500/m^3 (Fig. 12b). Highest values were observed in the inshore region and decreased with distance from shore. Abundances were generally higher than during previous August cruises.

Bosmina longirostris was the numerically dominant taxon in the inshore and middle depth regions. Immature Diaptomus and Cyclops spp. copepodites, and copepod nauplii also were common. In the offshore region, immature Diaptomus spp. copepodites were the most abundant group followed by Bosmina longirostris. Copepod nauplii and immature Cyclops spp. copepodites also were common offshore.

Biomass ranged from 37.2 to 95.6 mg/m^3 (Fig. 13b) and was highest in the middle depth zone. Bosmina longirostris and immature Diaptomus spp. copepodites were the major components of the inshore biomass, while in deeper waters, immature Diaptomus spp. copepodites, adult D. sicilis, and Limnocalanus macurus accounted for most of the biomass.

13 August 1981

Surface-water temperatures (Fig. 2q) ranged from 22.5 to 28.0 °C. Warmest water was found in the thermal plume with temperatures up to 4 C° higher than in ambient waters. Surface-water temperatures were slightly higher than corresponding values in August 1979 and 1980 and July 1981. Relatively high temperatures at DC-1 and NDC-.5-2 indicated the presence of a small thermal plume flowing to the northwest (Fig. 2q). Water column

temperatures were approximately 7 °C higher than in July 1981 (Fig. 2q). Secchi disc depths ranged from 3.0 m to 5.2 m (Fig. 3q). Water color generally was murky gray-green over the survey area.

Total zooplankton concentrations showed little spatial variation over the survey area and ranged from 15,500 to 39,900/m^3 (Fig. 12c). Zooplankton densities were lower than during previous August cruises.

In the inshore region, the zooplankton community was mainly composed of *Bosmina longirostris* which accounted for 60 to 80% of the population. Copepod nauplii and immature *Diaptomus* spp. copepodites also were common at most inshore stations while adult *Tropocyclops prasinus mexicanus* was abundant at one station (NDC-7-1). The dominant taxa in the middle and offshore zones were immature *Diaptomus* and *Cyclops* spp. copepodites with copepod nauplii, *Daphnia* spp. (primarily *D. retrocurva*), and *Bosmina longirostris* also abundant.

Biomass values ranged from 11.6 to 70.3 mg/m^3 (Fig. 13c). Biomass increased with depth and distance from shore reflecting the increased abundance of larger animals offshore. In the offshore region, biomass was composed mainly of immature *Diaptomus* spp. copepodites and *Daphnia* spp. while in the inshore region, *Bosmina longirostris* accounted for most of the biomass.

13 September 1979

Lake cooling had begun by the time of the September cruise, with surface-water temperatures ranging from 17.8 to 24.3 °C (Fig. 2r). A small thermal plume was detectable north and west of the plant (Fig. 2r). The lake had cooled since the previous month, but was still thermally stratified (Fig. 2r). Secchi disc depths ranged from 2.9 m to 5.0 m (Fig. 3r). Water color was

murky green at stations nearest shore and bright- or dark-green at deeper stations.

Total zooplankton abundance ranged from 15,300 to 41,600/m^3 (Fig. 14a) with highest concentrations in the middle region of the survey area. The numerically dominant taxon in the middle and inshore regions was *Bosmina longirostris*. Immature *Cyclops* spp. and *Diaptomus* spp. copepodites were the dominant taxa in the offshore region and of secondary abundance in the inshore region. *Daphnia* spp. were abundant at several stations throughout the survey area.

Biomass, which ranged from 12.6 to 59.1 mg/m^3 (Fig. 15a), also was greatest in the middle depth zone. *Bosmina longirostris* was the main component of the inshore biomass while immature *Diaptomus* and *Cyclops* spp. copepodites and *Daphnia* spp. accounted for most of the offshore biomass.

012 September 1980

There was evidence of an upwelling during the September 1980 cruise, with surface-water temperatures increasing from 15.3 °C in the inshore region to 20.5 °C in the offshore (Fig. 2s). Surface-water temperatures were lower than August 1980 and September 1979, especially in areas most affected by the upwelling. The thermal plume was small and weakly defined (Fig. 2s). Secchi disc transparencies (Fig. 3s) ranged from 1.8 m to 4.8 m and generally increased with distance offshore. Water color was murky- or gray-green in the inshore region, and bright gray- or blue-green in the offshore region.

Total zooplankton densities ranged from 7,100 to 31,300/m^3 (Fig. 14b). Although highest concentrations were again observed in the middle zone, abundances were lower than during the previous September cruises.

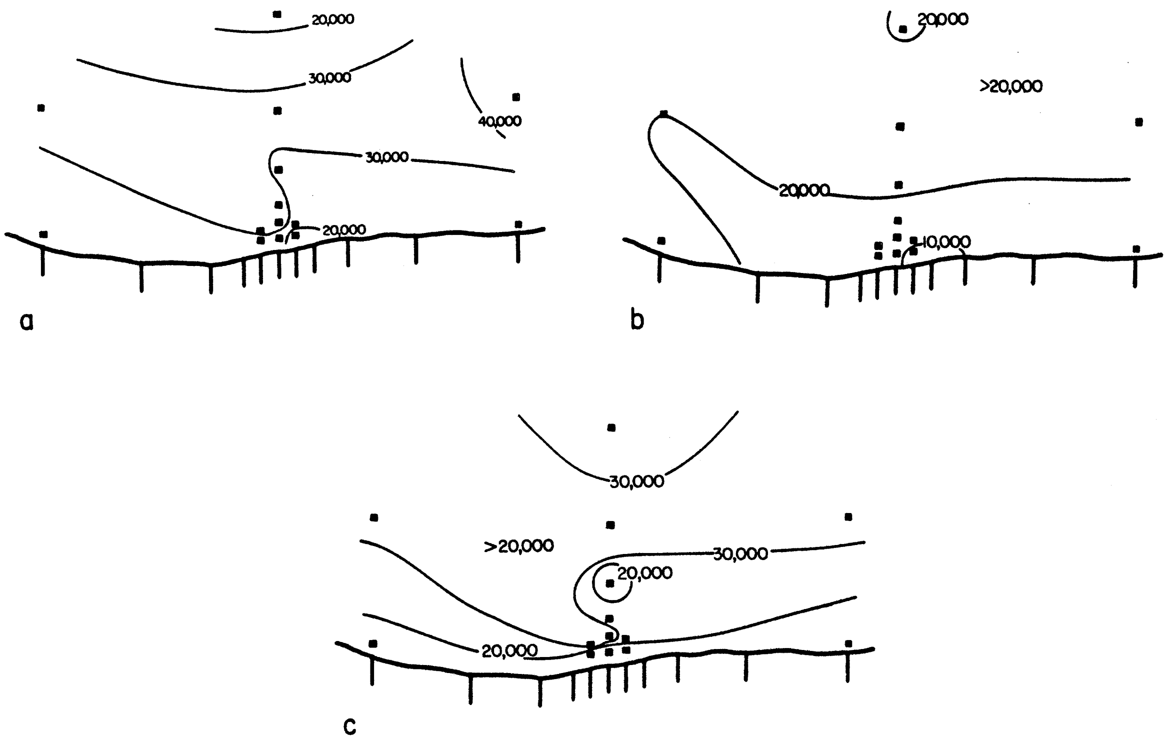


Fig. 14. The horizontal distribution of total zooplankton (number/m^3) collected on a) 13 September 1979, b) 12 September 1980, and c) 20 September 1981.

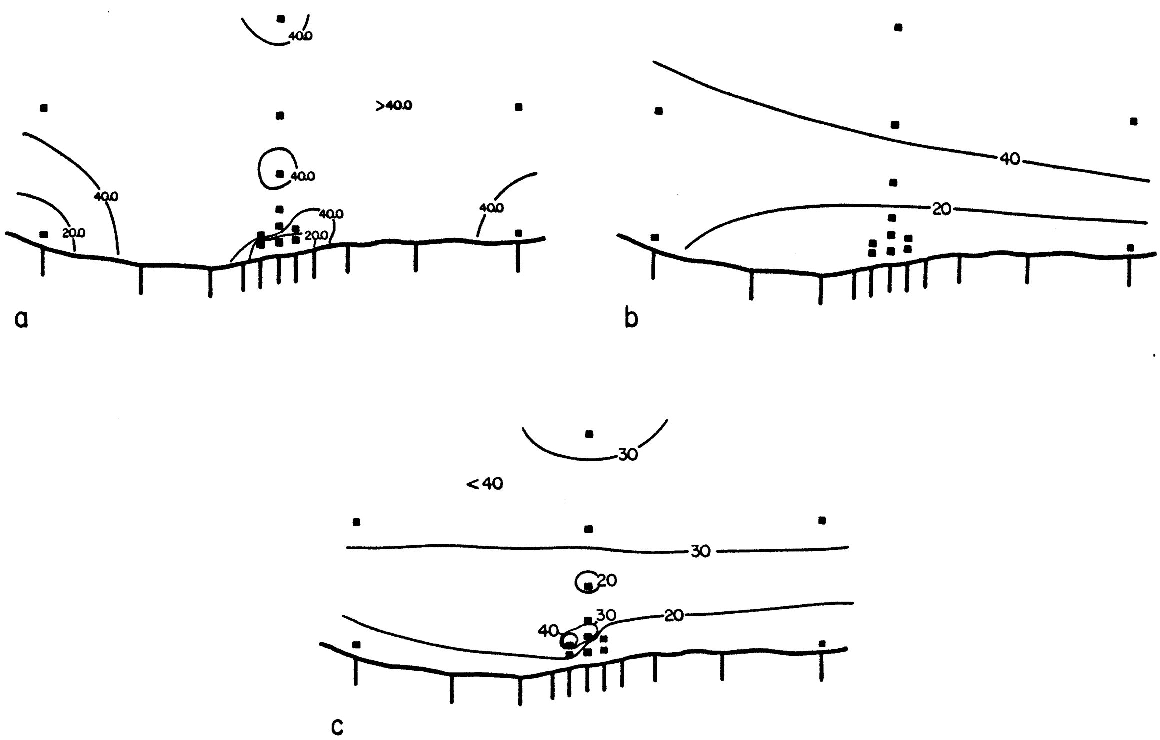


Fig. 15. The standing stock of zooplankton (mg dry weight/m^3) on a) 13 September 1979, b) 12 September 1980, and c) 20 September 1981.

Zooplankton populations in the inshore and middle zones were comprised mainly of Bosmina longirostris. Copepod nauplii and immature Cyclops spp. and Diaptomus spp. copepodites also were abundant. Immature Diaptomus spp. copepodites were the major component of the offshore zooplankton, followed by copepod nauplii and immature Cyclops spp. copepodites. Two rare species, Daphnia pulicaria (first observed in October 1978) and Mesocyclops edax were found in low numbers at several stations.

Biomass, which ranged from 5.7 to 58.1 mg/m^3, increased with distance from shore (Fig. 15b). Values were similar to those observed in September 1979. Bosmina longirostris accounted for much of the inshore biomass, while immature Diaptomus spp. copepodites were the largest component of the middle and offshore biomass. In the deepest offshore areas, large adult calanoids (Diaptomus sicilis and Limnocalanus macrurus), also comprised a major fraction of biomass.

20 September 1981

Surface-water temperatures ranged from 18.5 to 22.6 °C (Fig. 2t) and were lower than corresponding values observed in August 1981. The thermal plume was small and weakly defined (Fig. 2t). Thermocline erosion was evident (Fig. 2t). Secchi disc depth (Fig. 3t) ranged from 1.4 to 4.6 m. Water color was green at most stations.

Zooplankton ranged in abundance from 16,700 to 34,500/m^3 (Fig. 14c) with highest densities in the middle zones. Densities were slightly higher than those observed in September 1980 and similar to those observed in September 1979.

Bosmina longirostris and immature Diaptomus spp. copepodites were the most abundant components of the inshore zooplankton community: copepod nauplii also were abundant. Immature Diaptomus spp. copepodites was the main component of the offshore population. Also common were copepod nauplii, immature Cyclops spp. copepodites, adult Tropocyclops prasinus mexicanus, adult Diaptomus spp. (primarily D. minutus), and Bosmina longirostris.

Biomass ranged from 12.8 to 40.1 mg/m^3 (Fig. 15c). Highest values generally were observed in the middle depth zone and were lower than values observed during previous September cruises. Immature Diaptomus spp. copepodites was the major component of the biomass over the entire survey area. Bosmina longirostris also was a significant component of the inshore region biomass while adult Diaptomus minutus was a significant component of the offshore region biomass.

18 October 1979

Surface-water temperatures ranged from 13.6 to 17.2 °C (Fig. 2u). There was some evidence that the cruise was taken at the beginning of an upwelling. Relatively cool (<13 °C) water was observed flowing up the lake slope (Fig. 2u). Furthermore, intake water temperatures decreased between October 18 and 20, providing further evidence of an upwelling event. The thermal plume was small (Fig. 2u). Temperatures were lower than corresponding values in September 1979. Significant erosion of the thermocline had occurred with the lake showing little sign of thermal stratification (Fig. 2u). Secchi disc depths ranged from 1.4 m to 5.8 m (Fig. 3u). Water color was murky green at some inshore stations and bright- or blue-green elsewhere.

Zooplankton densities ranged from 26,000 to 137,000/m^3 (Fig. 16a). Highest abundances were observed in a small, inshore area (between the 5- and 15-m depth contours) south of the plant (Fig. 16a). These high abundances corresponded with high concentrations of Bosmina longirostris (Fig. 16s).

The zooplankton community was dominated by Bosmina longirostris (Fig. 16s), immature Cyclops spp. (Fig. 16g) and Diaptomus spp. copepodites (Fig. 16m), and Daphnia spp. (Fig. 16y) (mainly D. retrocurva). Bosmina longirostris were especially abundant in the inshore and middle zones where this taxon generally comprised 40 to 70% of the population. Daphnia pulicaria and Mesocyclops edax were found in low numbers (<20/m^3) at several stations over the survey area.

Biomass, which ranged from 32.2 to 154.8 mg/m^3 (Fig. 17a), was greatest in the area of high zooplankton abundance. Bosmina longirostris was generally the main component of the inshore biomass while immature Cyclops spp. and Diaptomus spp. copepodites, and Daphnia spp. accounted for most of the biomass in the middle and offshore areas. Daphnia spp. were an especially significant biomass component in the area of high biomass at the north end of the survey area.

15 October 1980

Lake cooling continued from the previous month. Surface water temperatures ranged from 11.8 to 15.7 °C (Fig. 2v). Water temperatures were lower than those recorded in October 1979. The thermal plume was small (Fig. 2v). Significant lake cooling had occurred between the September and October cruises and the thermocline was strongly eroded (Fig. 2v). Secchi disc depths ranged from 1.2 m to 5.1 m (Fig. 3v). Turbidity was greatest in

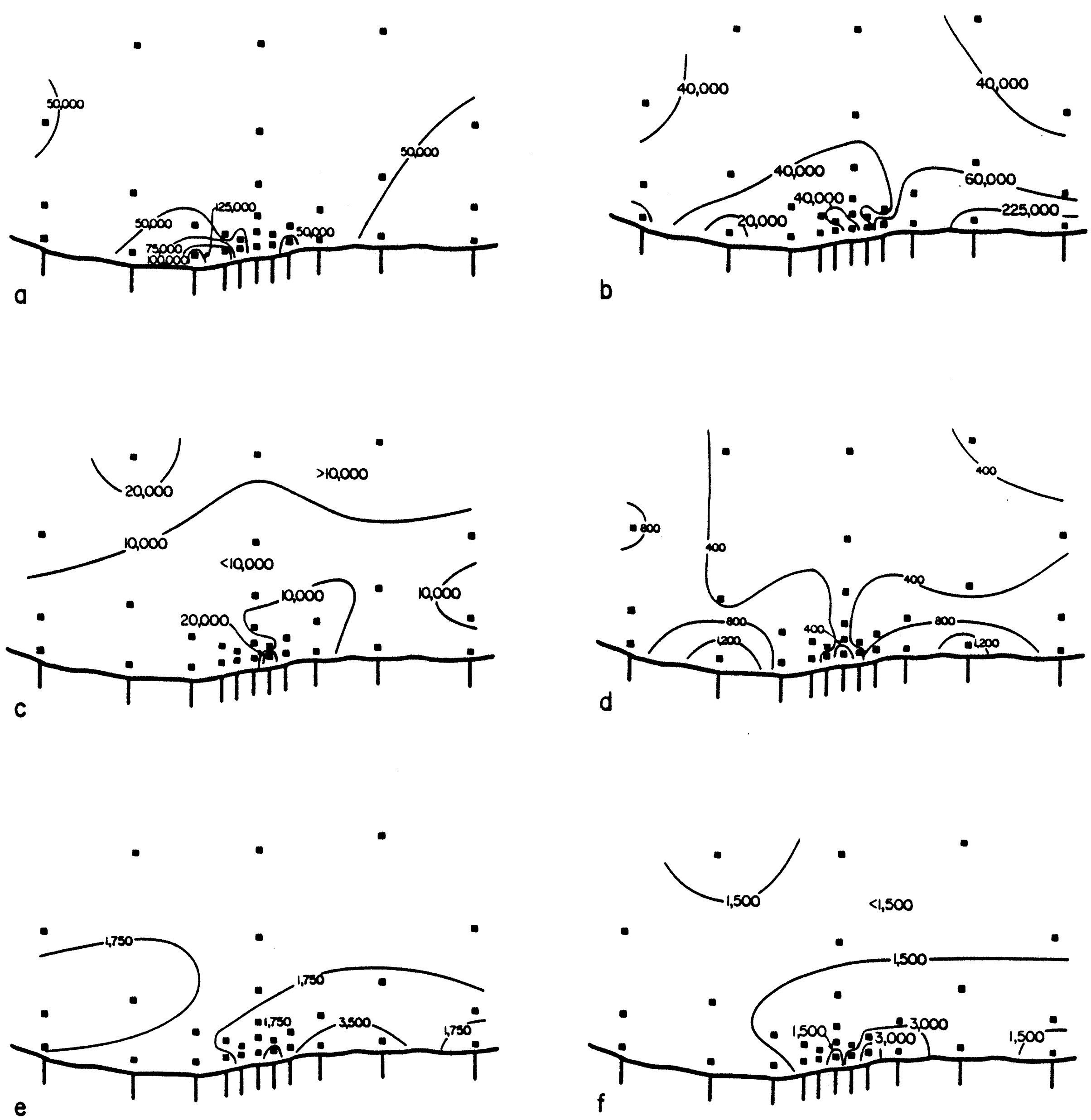


Fig. 16. Horizontal distribution (number/m^3) of total zooplankton and major taxa collected on 18 October 1979, 15 October 1980, and 14 October 1981 respectively. a), b), and c) total zooplankton; d), e), and f), copepod nauplii;

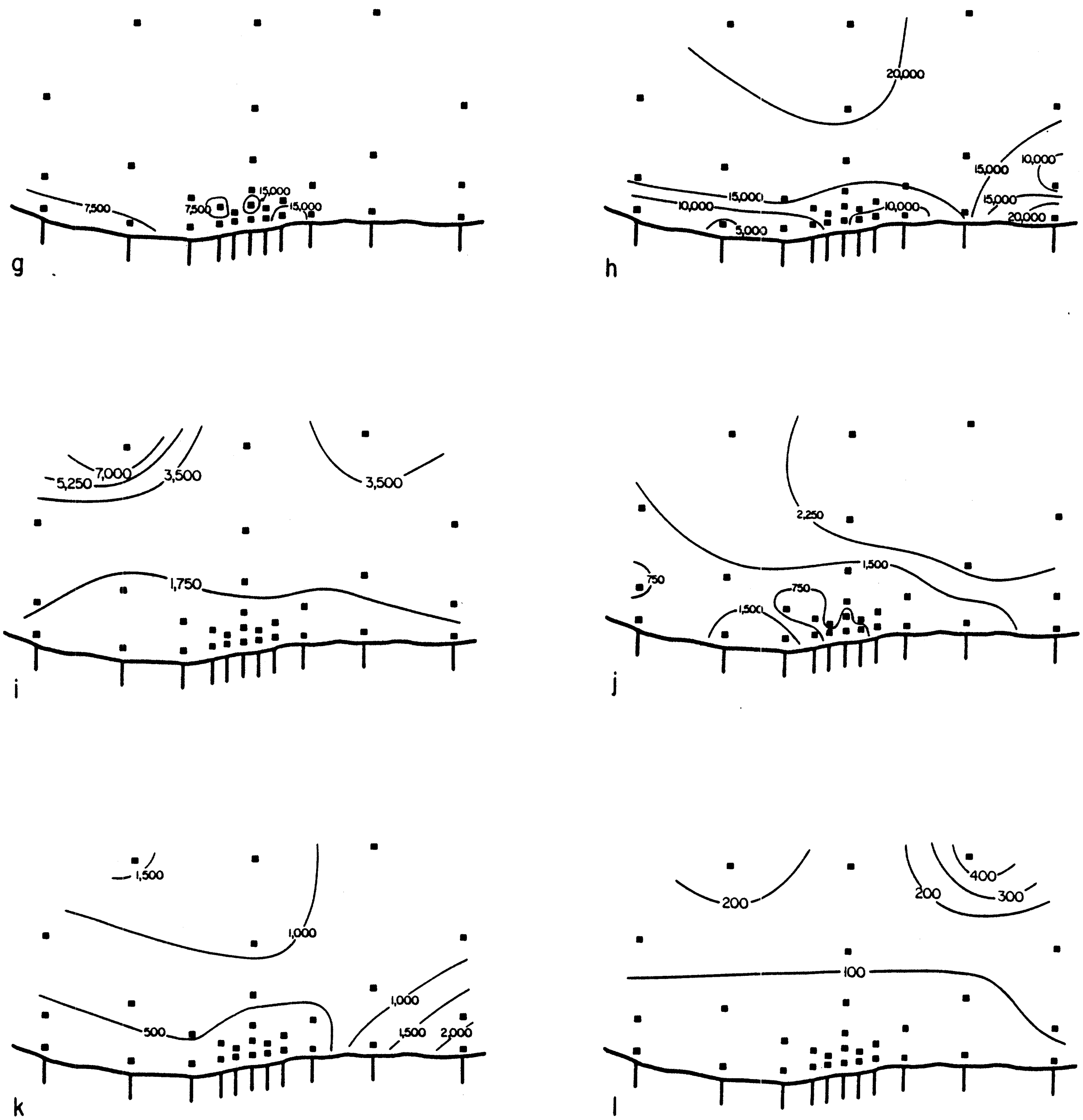


Fig. 16. Continued. g), h), and i) *Cyclops* spp. C1-C5; j), k), and l) *Cyclops* spp. C6;

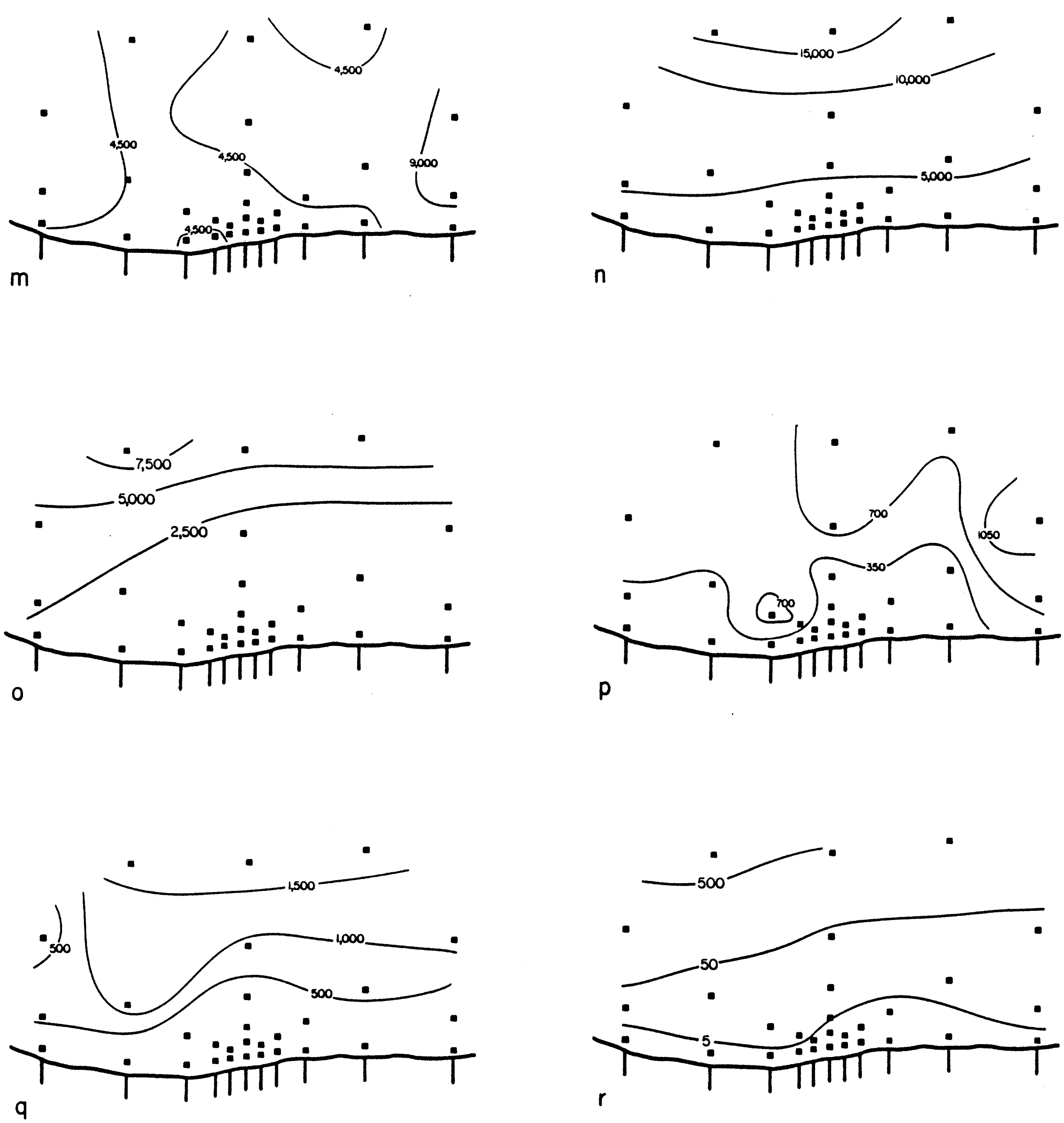


Fig. 16. Continued. m), n), and o) <u>Diaptomus</u> spp. C1-C5; p), q), and r) <u>Diaptomus</u> spp. C6;

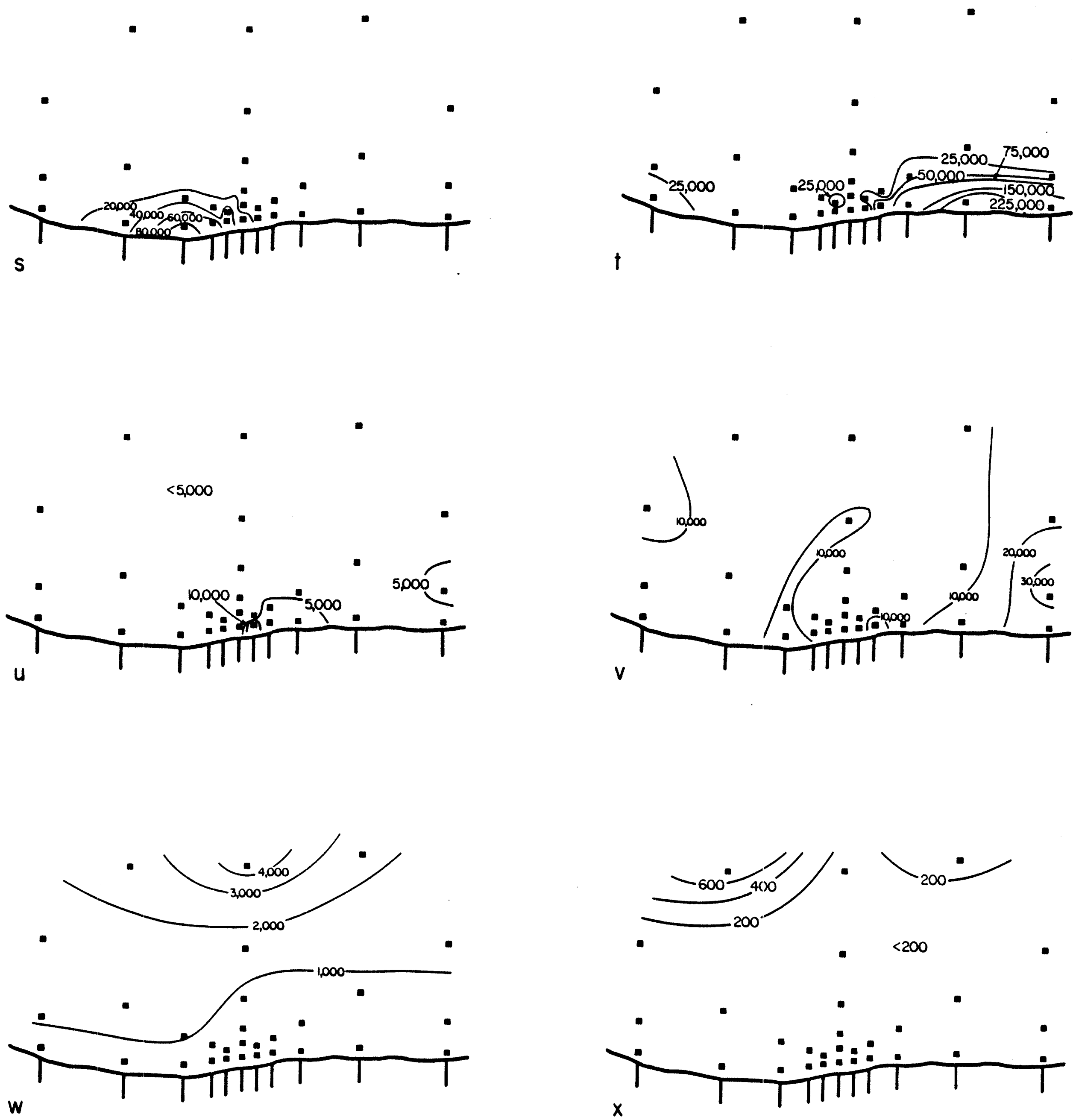


Fig. 16. Continued. s), t), and u) Bosmina longirostris; v), w), and x) Eubosmina coregoni;

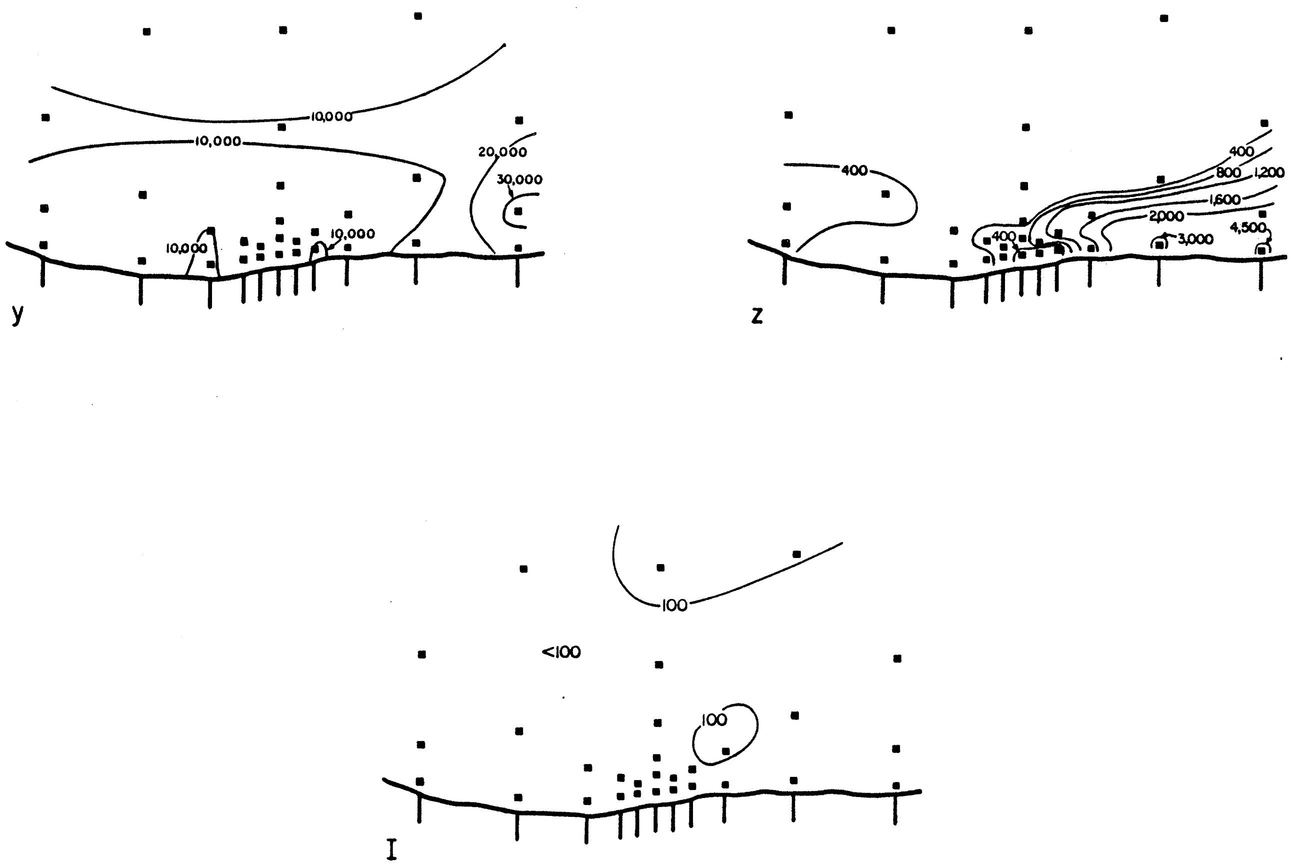


Fig. 16. Concluded. y), z), I) Daphnia spp.

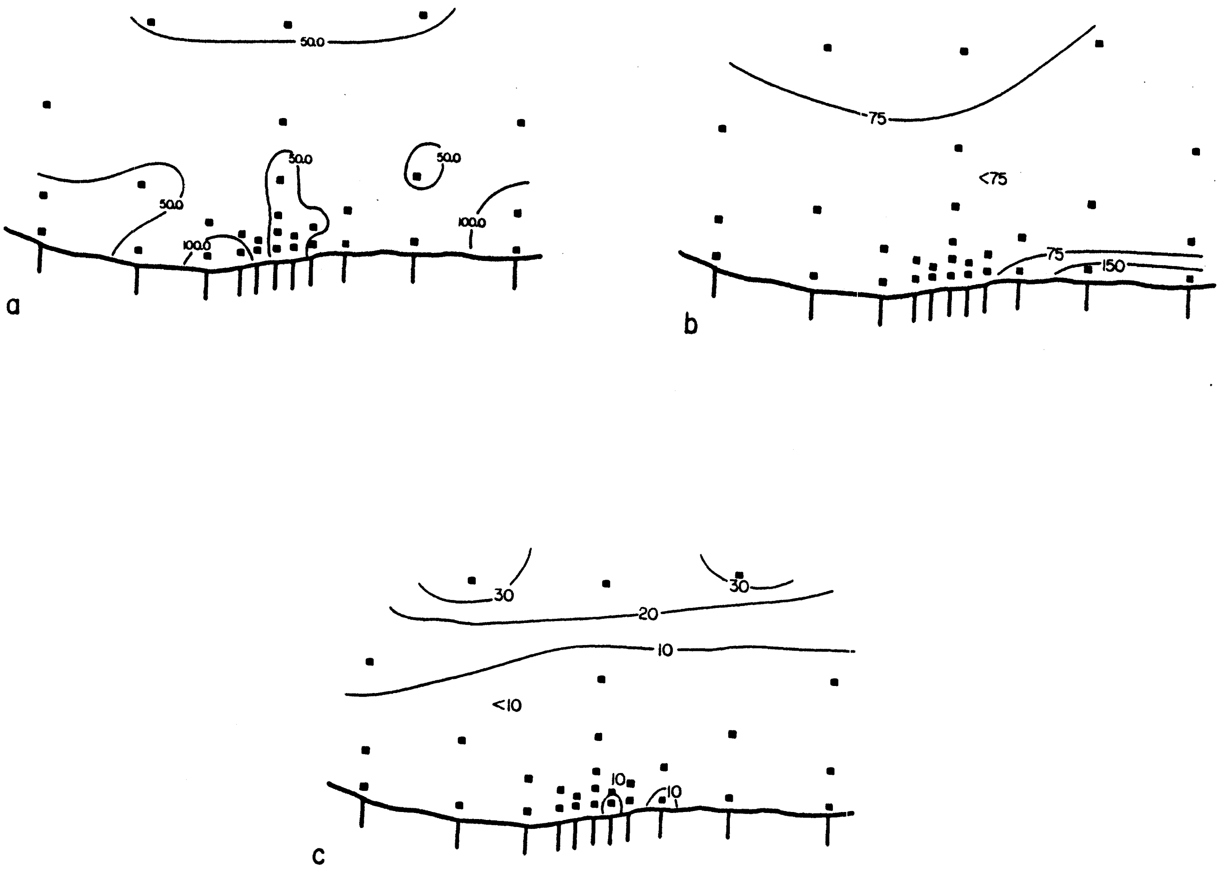


Fig. 17. The standing stock of zooplankton (mg dry weight/m^3) on a) 18 October 1979, b) 15 October 1980, and c) 14 October 1981.

the inshore region where the water color was murky green. At deeper stations, where Secchi disc depths exceeded 4.5 m, the water was blue-green.

Total zooplankton densities ranged from 1,300 to 265,000/m^3 (Fig. 16b). Highest zooplankton concentrations were in the inshore area north of the plant, and, as in October 1979, were associated with high *Bosmina longirostris* concentrations (Fig. 16t).

In the inshore region, the zooplankton population was numerically dominated by *Bosmina longirostris* (Fig. 16t) which comprised 40 to 87% of the community. Immature *Cyclops* spp. copepodites (Fig. 16h) were also abundant in the inshore region and dominated the offshore population. Immature *Diaptomus* spp. copepodites (Fig. 16n) were of secondary abundance offshore; *Bosmina longirostris* also was numerous. *Mesocyclops edax* was found at one station (SDC-4-4) in low numbers (11/m^3).

Biomass, which ranged from 11.0 to 230.3 mg/m^3 (Fig. 17b), was generally higher in the offshore region except for the small area of high abundance in the inshore region. *Bosmina longirostris* accounted for most of the inshore biomass, while immature *Diaptomus* spp. copepodites was the major component of the offshore biomass. Immature *Cyclops* spp. copepodites, adult *D. sicilis*, and *Daphnia* spp. also were significant components of the offshore biomass.

14 October 1981

Surface-water temperatures ranged from 13.1 to 15.7 °C (Fig. 2w). Temperatures decreased substantially from September 1981 and were intermediate to those of October 1979 and October 1980. The thermal plume was small and weakly defined (Fig. 2w). The epilimnion had mixed down to depths of 30 m

(Fig. 2w). Secchi disc transparencies varied from 1.9 m to 6.6 m (Fig. 3w). Water color was gray- or blue-green.

Zooplankton densities, which ranged from 3,600 to 23,500/m^3 (Fig. 16c), were lower than during the October 1979 and 1980 cruises. Zooplankton concentrations were greatest offshore and in a small inshore area north of the plant where *Bosmina longirostris* densities (Fig. 16u) were highest. With the exception of *Bosmina longirostris* and copepod nauplii, most zooplankton taxa occurred in their greatest abundances in the offshore region.

Bosmina longirostris and copepod nauplii were the numerically dominant taxa in the inshore and middle zones. Immature *Diaptomus* spp. and *Cyclops* spp. copepodites (Figs. 16 o,i), which were of secondary dominance in the inshore region, were the numerically dominant taxa in the offshore region. Copepod nauplii and *Bosmina longirostris* were also abundant offshore. Adult *Tropocyclops prasinus mexicanus* were common over the whole survey area. As in previous Octobers, *Mesocyclops edax* was found in low concentrations (<10/m^3) and generally was most abundant in the offshore region.

Biomass ranged from 2.7 to 32.9 mg/m^3 (Fig. 17c) and generally increased with distance from shore. *Bosmina longirostris* and immature *Diaptomus* spp. copepodites accounted for most of the inshore biomass, while immature *Diaptomus* spp. copepodites and adult *Limnocalanus macrurus* were the major components of the offshore biomass. Immature *Cyclops* spp. copepodites and *Bosmina longirostris* were secondary components of the offshore biomass.

14 November 1979

Lake cooling was evident. Surface-water temperatures ranged from 7.4 to 10.3 °C (Fig. 2x) and were lower than corresponding values observed during the

October 1979 cruise. A small thermal plume (Fig. 2x) was centered slightly north and west of the plant. The lake was thermally well-mixed (Fig. 2x). Secchi disc readings readings ranged from 3.1 m to 7.2 m (Fig. 3x). Water color was not recorded.

Total zooplankton densities ranged from 8,900 to 18,500/m^3 (Fig. 18a). Lowest densities were observed at the stations closest to shore, near the thermal plume.

The numerically dominant zooplankton taxa in the middle and inshore zones were *Bosmina longirostris* and immature *Cyclops* spp. copepodites. Immature *Diaptomus* spp. copepodites also were abundant in these areas. In the offshore zones, immature *Cyclops* spp. and *Diaptomus* spp. copepodites dominated. Copepod nauplii and *Eubosmina coregoni* were common over the survey area. *Daphnia pulicaria* was found in low numbers (6/m^3) at one station (NDC-.5-2).

Biomass ranged from 13.5 to 39.7 mg/m^3 (Fig. 19a) and was generally higher offshore where larger organisms were more abundant. *Bosmina longirostris* and immature *Cyclops* spp. and *Diaptomus* spp. copepodites comprised the major fraction of inshore biomass while immature *Diaptomus* spp. and *Cyclops* spp. copepodites, and adult *Diaptomus* spp. (especially *D. sicilis*) accounted for most of the offshore biomass.

12 November 1980

Surface-water temperatures ranged from 7.8 to 11.0 °C (Fig. 2y). The thermal plume was small and weakly defined (Fig. 2y). Lake cooling continued with surface-water temperatures lower than during the October 1980 cruise. Temperatures were slightly warmer than November 1979. The water column was thermally well-mixed down to depths of 40 m (Fig. 2y). Secchi disc depths

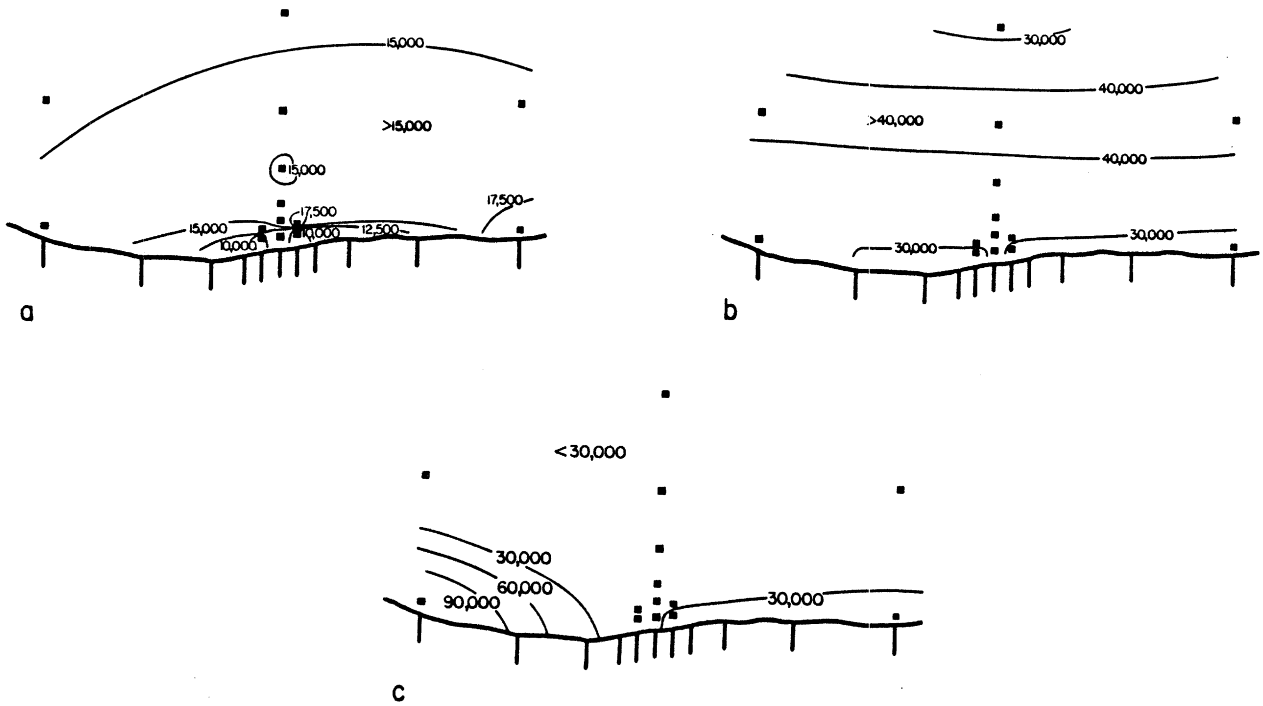


Fig. 18. The horizontal distribution of total zooplankton (number/m^3) collected on a) 14 November 1979, b) 12 November 1980, and c) 11 November 1981.

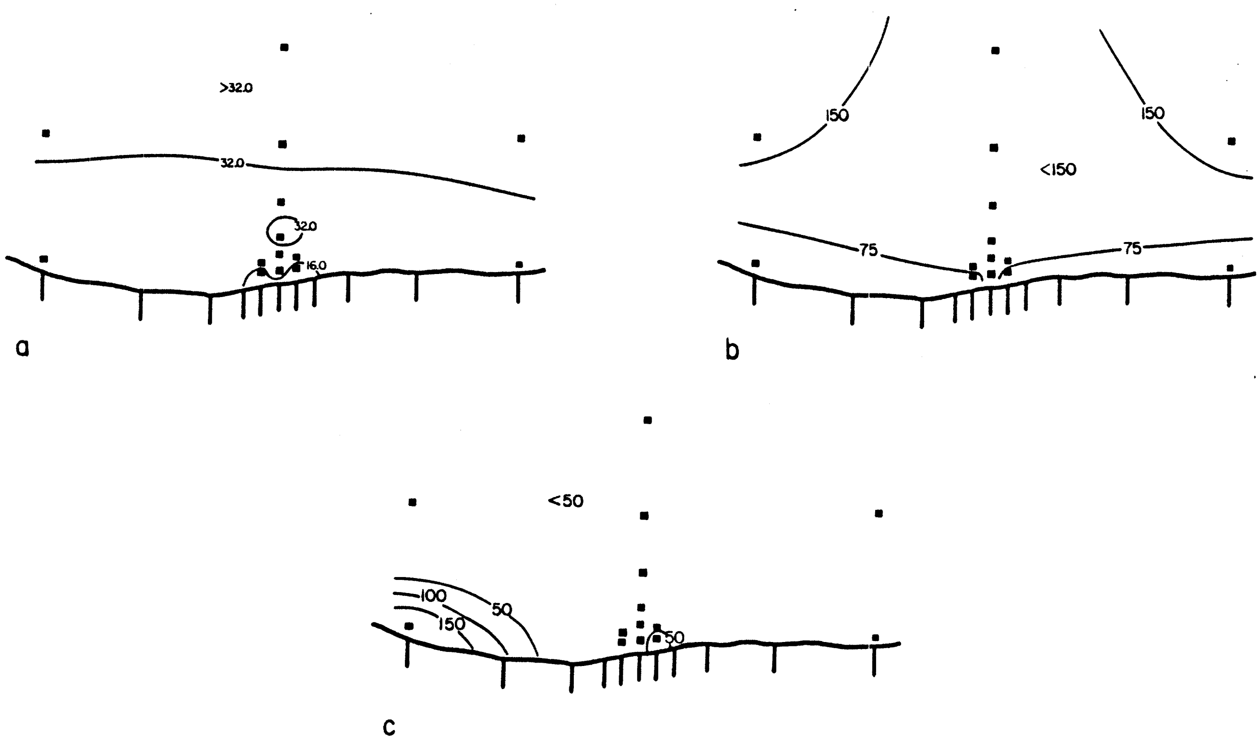


Fig. 19. The standing stock of zooplankton (mg dry weight/m^3) on a) 14 November 1979, b) 12 November 1980, and c) 11 November 1981.

(Fig. 3y) ranged from 1.5 m to 6.3 m. In nearshore areas, the dominant water color was murky green. In offshore areas, water color was grayish- or blue-green.

Total zooplankton concentrations were higher than during the previous November cruise and ranged from 20,700 to 43,300/m^3 (Fig. 18b). Abundances were generally higher in the offshore region.

The zooplankton community was composed mainly of immature *Cyclops* spp. and *Diaptomus* spp. copepodites except at a few inshore stations where *Bosmina longirostris* was more abundant. Adult *Diaptomus* spp. (primarily *D. ashlandi*) also was abundant over the survey area.

Biomass, which ranged from 46.3 to 179.4 mg/m^3 (Fig. 19b), was higher in the offshore region. Immature and adult *Diaptomus* spp. were the main components of the biomass over the whole survey area.

11 November 1981

Surface-water temperatures ranged from 9.2 to 11.5 °C (Fig. 2z). The thermal plume was weakly defined (Fig. 2z). Water temperatures decreased from the previous month and were similar to those of November 1980. The water column was thermally well-mixed (Fig. 2z). Secchi disc depths (Fig. 3z) ranged from 1.5 m to 5.0 m. The dominant water color over the survey area was murky green.

Total zooplankton densities ranged from 10,000 to 116,00/m^3 (Fig. 18c). Abundances generally were greater in the inshore region than in the offshore region. The high zooplankton concentration at SDC-7-1 was associated with large numbers of *Bosmina longirostris* (>100,000/m^3).

Bosmina longirostris, and immature Diaptomus spp. and Cyclops spp. copepodites were the major components of the zooplankton over the survey area. The inshore community was dominated by Bosmina longirostris while immature Diaptomus spp. and Cyclops spp. copepodites were the most abundant offshore taxa.

Biomass ranged from 17.3 to 195.8 mg/m^3 (Fig. 19c) and, except for SDC-7-1, was relatively uniform over the survey area. The inshore biomass was composed mainly of Bosmina longirostris and immature Diaptomus spp. copepodites while in the offshore region, immature Diaptomus spp. and Cyclops spp. copepodites accounted for most of the biomass.

Principal Component Analysis of 1979 to 1982 Data

A total of ten analyses were performed utilizing the major survey data from the April, July, and October, 1979, 1980, and 1981, and April 1982 cruises. In all principal component analyses, the first principal component accounted for 50 to 76% of the total variance while the second principal component accounted for an additional 10 to 34% of the variance (Table 1). These values are similar to those reported for 1973 - 1978 data (Evans 1975, Evans et al. 1978a, 1980, 1982).

The first principal component (PC1) was highly correlated to station depth ($|r| > 0.6$) except in the April 1980 ($|r| = 0.19$, Table 2a) and October 1979 ($|r| = 0.34$, Table 2c) analyses. The strength of the correlation between PC1 and total zooplankton numbers varied considerably ($0.08 < |r| < 0.85$, Table 2) from analysis to analysis. Previous analyses of the 1973-1978 data have also shown a strong relationship between PC1 and depth (Evans 1975, Evans et al. 1978, 1980, 1982).

Table 1. The percentage of total variance explained by principal components 1 (PC 1), 2 (PC 2), and the two components combined in analyses of major survey samples.

	April			
PC	1979	1980	1981	1982
PC 1	49.6	71.0	76.2	64.3
PC 2	34.3	15.6	11.3	18.6
Sum	83.9	86.6	87.5	82.9

	July		
PC	1979	1980	1981
PC 1	56.1	74.0	75.8
PC 2	14.3	9.6	10.3
Sum	70.4	83.6	86.1

	October		
PC	1979	1980	1981
PC 1	56.2	65.3	68.1
PC 2	21.0	22.2	14.6
Sum	77.2	87.5	82.7

Table 2a. Correlations (r) between zooplankton (log #/m^3 + 1) taxa used in the analyses, station depth, total zooplankton, and the first principal component for April 1979-1982.

	PC1 April			
Taxon	1979	1980	1981	1982
Copepod nauplii	-.75**	.58*	-.34	.34
Cyclopoid copepods C1-C5	.92**	.91*	.62**	.75**
Cyclops spp. C6	.51**	.97*	.65**	.72**
Diaptomus spp. C1-C5	.03	.62*	.81**	.85**
Diaptomus spp. C6	.67**	.61*	.76**	.73**
Limnocalanus macrurus C1-C6	.24	-.00	.95**	.86**
Station Depth	.60*	.19	.85**	.87**
Total Zooplankton	-.08	.85*	.33	.64**

*P<0.05
**P<0.01

Table 2b. Correlations (r) between zooplankton (log #/m^3 + 1) taxa used in the analyses, station depth, total zooplankton, and the first principal component for July 1979-1981.

	PC1 July		
Taxon	1979	1980	1981
Copepod nauplii	.08	-.76**	.72**
Cyclopoid copepods C1-C5	.46*	.92**	.49**
Cyclops spp. C6	.81**	.97**	.95**
Diaptomus spp. C1-C5	.82**	.96**	.97**
Diaptomus spp. C6	.88**	.93**	.91
Eurytemora affinis C1-C6	--	-.51**	-.12
Limnocalanus macrurus C1-C6	--	.36	--
Bosmina longirostris	.69**	-.20	.35
Daphnia spp.	.30	.88**	.92**
Minor cladocerans	.35	.33	--
Asplanchna spp.	-.27	-.65**	-.81**
Station Depth	.66**	.88**	.90**
Total Zooplankton	.76**	.35	.48*

*P<0.05
**P<0.01

Table 2c. Correlations (r) between zooplankton (log #/m^3 + 1) taxa used in the analyses, station depth, total zooplankton, and the first principal component for October 1979-1981.

Taxon	PC1 October 1979	PC1 October 1980	PC1 October 1981
Copepod nauplii	.66**	.35	-.14
Cyclopoid copepods C1-C5	-.37*	-.74**	.86**
Cyclops spp. C6	-.14	-.56**	.92**
Tropocyclops prasinus m. C1-C6	.86**	--	.61**
Diaptomus spp. C1-C5	.21	-.92**	.71**
Diaptomus spp. C6	.20	-.84**	.90**
Epischura lacustris C1-C6	.77**	.24	--
Eurytemora affinis C1-C6	--	.93**	-.07
Bosmina longirostris	.67**	.81**	-.43*
Daphnia spp.	.62**	-.91**	.72**
Eubosmina coregoni	.92*	.19	--
Asplanchna spp.	--	--	.77**
Station Depth	-.34	-.94**	.85**
Total Zooplankton	.78**	.23	.53**

*P<0.05
**P<0.01

The environmental factor(s) related to the second principal component (PC2) was not identified. PC2 generally had low correlations with station depth. Correlations of PC2 with total zooplankton ranged widely ($0.11 < |r| < 0.73$, Table 3). Note that the sign of the correlations between the principal components and depth or total zooplankton densities is an artifact of the analysis and has little interpretative meaning. Only the strength of these correlations is important. However, the sign of the correlations between principal components and the transformed taxa densities actually used in an analysis is important in defining assemblages of zooplankton.

April 1979

PC1 was strongly related to depth in April 1979 (Table 2a). This is evident in the ordination of stations by their principal component scores (Fig. 20a): shallow-water stations had low PC1 values while deepwater stations had high PC1 values. The nearshore region had not warmed appreciably in 1979, but large depth gradients in percentage composition of copepod nauplii, *Diaptomus* spp. copepodites, and to some extent, *Cyclops* copepodites occurred (Figs. 21a and 22a). PC1 was negatively correlated with copepod nauplii abundance, but positively correlated with the abundances of all other taxa (Table 2a). The inshore region was characterized by relatively high concentrations of copepod nauplii, while the offshore region was characterized by relatively high concentrations of *Diaptomus* spp. and *Cyclops* spp. copepodites. The lack of a strong relationship between PC1 and total zooplankton observed in April 1979 ($|r|=0.08$) suggests that PC1 is more a measure of community structure than of abundance.

Table 3a. Correlations (r) between zooplankton (log #/m^3 + 1) taxa used in the analyses, station depth, total zooplankton, and the second principal component for April 1979-1982.

	PC2 April			
Taxon	1979	1980	1981	1982
Copepod nauplii	.10	.39*	.26	.09
Cyclopoid copepods C1-C5	-.06	-.02	-.55**	-.17
Cyclops spp. C6	.73**	-.03	-.61**	-.42*
Diaptomus spp. C1-C5	.09	.65**	.26	.29
Diaptomus spp. C6	.09	.57**	.29	-.14
Limnocalanus macrurus C1-C6	.95**	.17	.04	.59**
Station Depth	-.40*	.84**	-.12	.19
Total Zooplankton	.53**	.37*	.32	.11

*P<0.05
**P<0.01

Table 3b. Correlations (r) between zooplankton (log #/m^3 + 1) taxa used in the analyses, station depth, total zooplankton, and the second principal component for July 1979-1981.

	PC2 July		
Taxon	1979	1980	1981
Copepod nauplii	.78**	.29	.36
Cyclopoid copepods C1-C5	.73**	.22	.69**
Cyclops spp. C6	.13	.13	-.13
Diaptomus spp. C1-C5	-.33	.12	-.07
Diaptomus spp. C6	-.22	.05	-.28
Eurytemora affinis C1-C6	--	.38*	.53**
Limnocalanus macrurus C1-C6	--	-.41*	--
Bosmina longirostris	.45*	.61**	.82**
Daphnia spp.	.75**	.45*	.01
Minor cladocerans	-.07	.19	--
Asplanchna spp.	.23	.25	.16
Station Depth	-.46*	-.08	-.19
Total Zooplankton	.54**	.68**	.73**

*P<0.05
**P<0.01

Table 3c. Correlations (r) between zooplankton (log #/m^3 + 1) taxa used in the analyses, station depth, total zooplankton, and the second principal component for October 1979-1981.

Taxon	PC2 October 1979	PC2 October 1980	PC2 October 1981
Copepod nauplii	.12	.54**	.68**
Cyclopoid copepods C1-C5	.17	.31	.37*
Cyclops spp. C6	-.74**	.44*	.29
Tropocyclops prasinus m. C1-C6	-.04	--	.62**
Diaptomus spp. C1-C5	-.68**	.16	.19
Diaptomus spp. C6	-.85**	.33	.02
Epischura lacustris C1-C6	-.40*	.74**	--
Eurytemora affinis C1-C6	--	.26	.80**
Bosmina longirostris	.46*	.40*	.60**
Daphnia spp.	-.59**	.13	.02
Eubosmina coregoni	.17	.75**	--
Asplanchna spp.	--	--	.55**
Station Depth	-.68**	-.03	.17
Total Zooplankton	.26	.73**	.72**

*P<0.05
**P<0.01

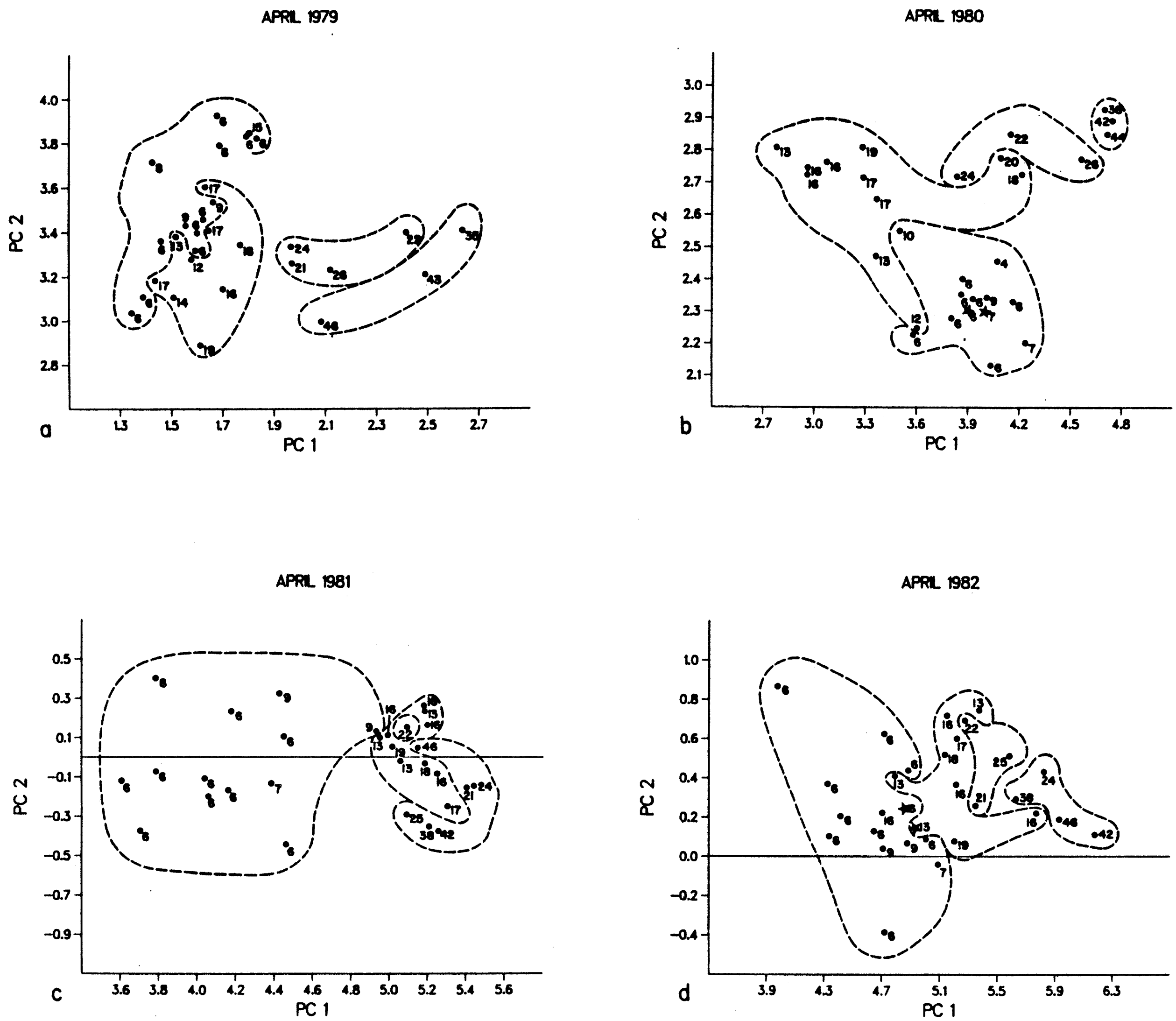


Fig. 20. Principal component ordination of survey stations sampled on a) 12 April 1979, b) 10 April 1980, c) 10 April 1981, and d) 15 April 1982. Station depth (m) is noted next to each point. Dotted lines roughly separate stations of three depth intervals: 5-10 m, 10-20 m, and 20-50 m. ★ indicates stations in the thermal plume.

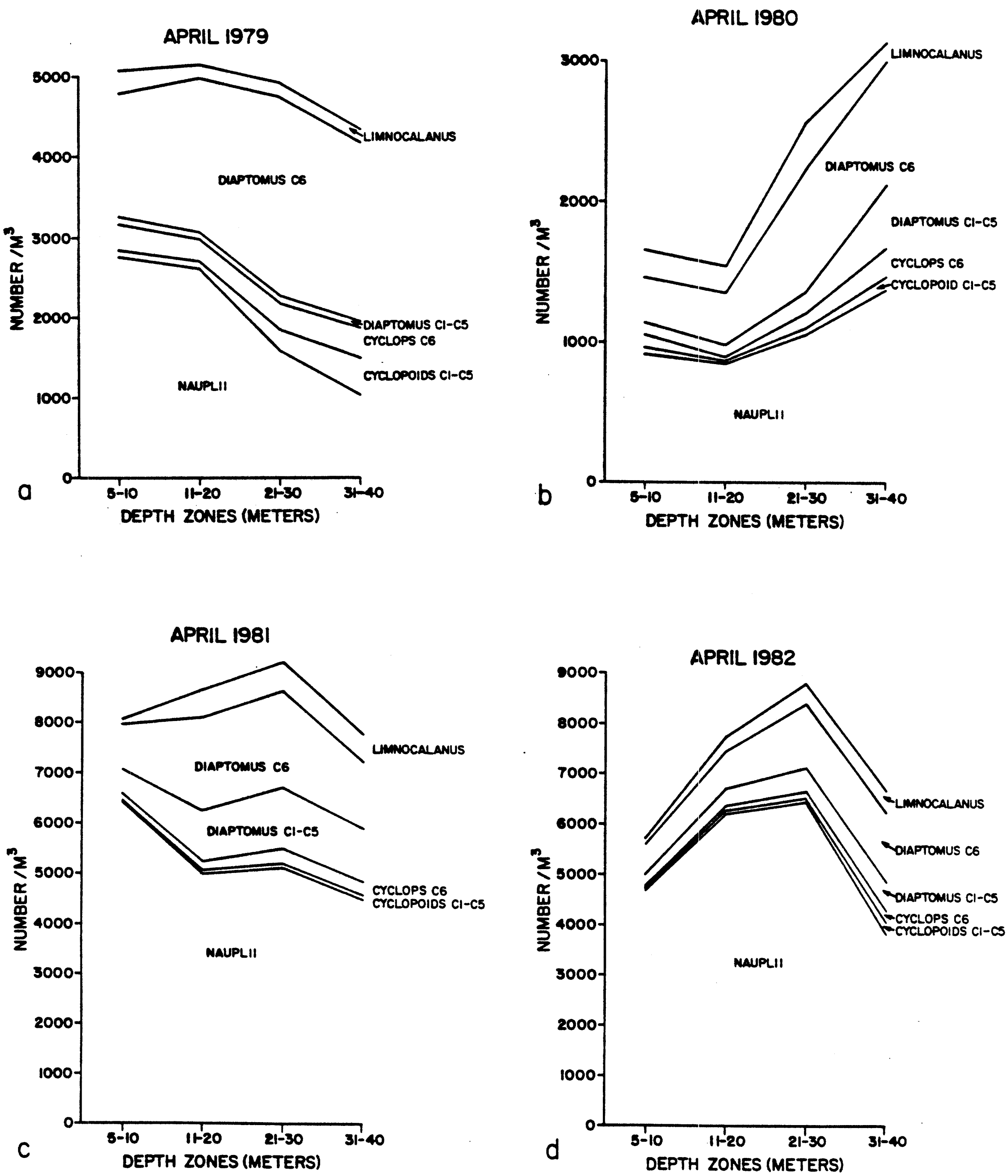


Fig. 21. Mean densities of zooplankton taxa for four depth zones (5-10 m, 10-20 m, 20-30 m, and 30-50 m). a) 12 April 1979, b) 10 April 1980 c) 10 April 1981, and d) 15 April 1982.

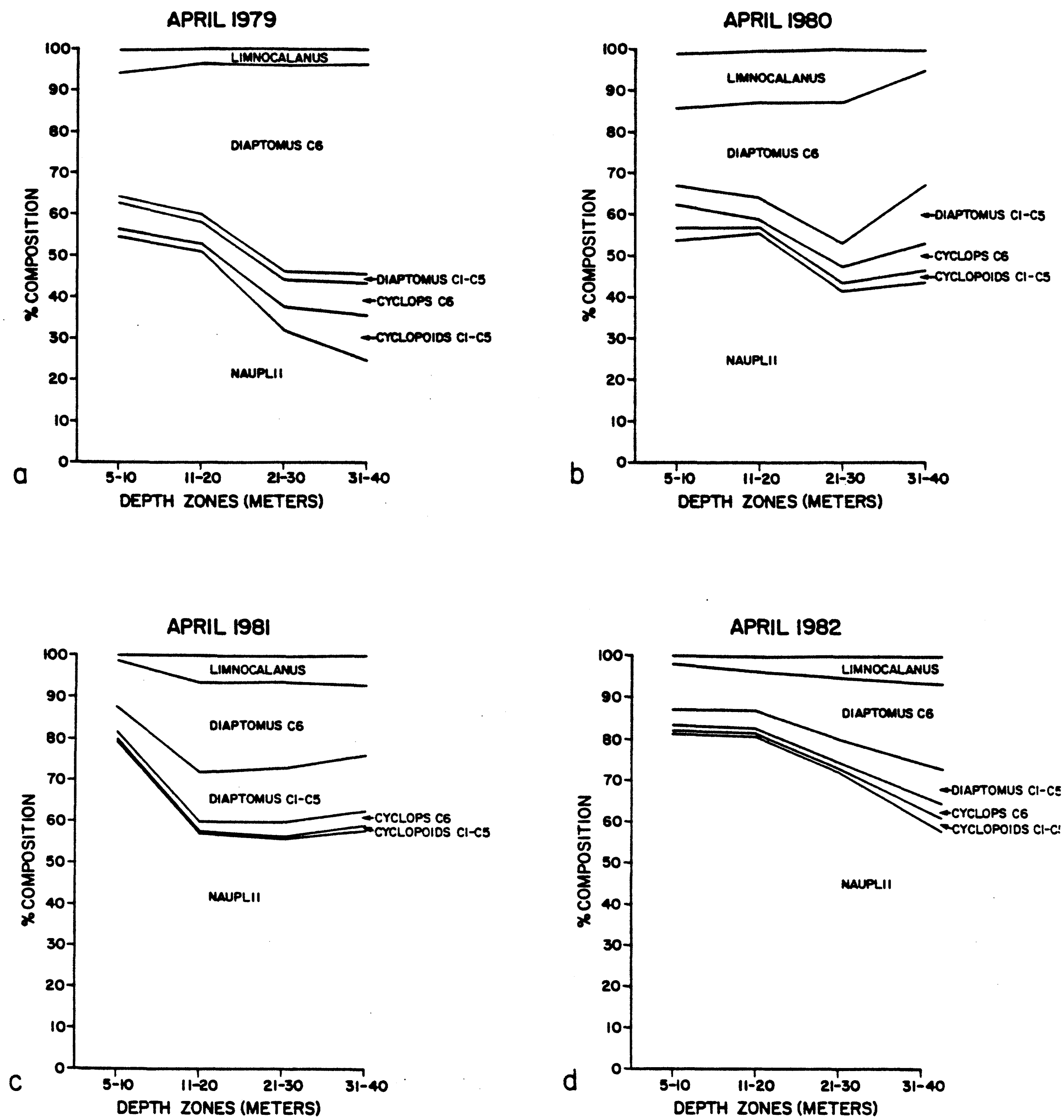


Fig. 22. Mean composition of zooplankton taxa for four depth zones (5-10 m, 10-20 m, 20-30 m, and 30-50 m). a) 12 April 1979, b) 10 April 1980, c) 10 April 1981, and d) 15 April 1982.

April 1980

There was a relatively weak relationship between PC1 and depth for the April 1980 analysis (Table 2a and Fig. 20b). The lake had not warmed appreciably by the time the April 1980 cruise was conducted. Most taxa used in the analysis were less abundant in the inshore than the offshore, with the exception of Limnocalanus macrurus copepodites (Figs. 21b and 22b). Previous analyses (Evans et al. 1978a, 1982) indicated that the strength of the PC1:depth relationship increased with increased warming of inshore water. In April 1980, all taxa were positively correlated with PC1, suggesting that PC1 represents zooplankton abundance. The lack of a strong relationship between PC1 and depth suggests that zooplankton abundances were somewhat depth-independent. There was no evidence that zooplankton community structure in the thermal plume was significantly different from that in ambient inshore waters.

April 1981

Principal component analysis results for April 1981 were very similar to those of April 1979. Inshore waters had warmed slightly more by the 1981 cruise than for other years. The relationship between PC1 and depth was strong (Table 2a and Fig. 20c). As in 1979, PC1 was negatively correlated with copepod nauplii and positively correlated with all other taxa, indicating an inshore region characterized by relatively high concentrations of copepod nauplii and an offshore region characterized by relatively high concentrations of Diaptomus spp. and Cyclops spp. copepodites (Figs. 21c and 22c). The correlation between PC1 and total zooplankton was weak ($|r|=0.33$) and suggests

that PC1 is more a measure of community structure than of abundance in this analysis.

April 1982

The relationship between PC1 and depth was strong in 1982 (Table 2a and Fig. 20d). Only slight warming of inshore waters occurred by the April 1982 cruise. There was only a moderate depth gradient in percentage composition of copepod nauplii, *Diaptomus* spp. and *Cyclopos* spp. copepodites (Fig. 21d). With the exception of copepod nauplii, taxa abundances were positively correlated with PC1. The PC1:copepod nauplii relationship was positive, but not significant. The abundance of all taxa but nauplii increased from the inshore to the offshore (Fig. 22d). There was no evidence of significant differences in zooplankton community structure between plume and ambient inshore region stations.

July 1979

Principal component 1 from the July 1979 analysis was moderately correlated with depth ($|r|=0.66$). Abundances of adult *Cyclops* spp. and immature and adult *Diaptomus* spp. copepodites increased with station depth. The slightly lower nearshore water temperatures in July 1979 indicate that an upwelling may have preceded the sampling. This may have disrupted the typically-observed spatial gradients in zooplankton community structure.

July 1980

In July 1980, PC1 was highly correlated with station depth (Table 2b). The ordination of stations by their principal component scores shows a distinct clustering of stations by depth (Fig. 23b). Two zooplankton

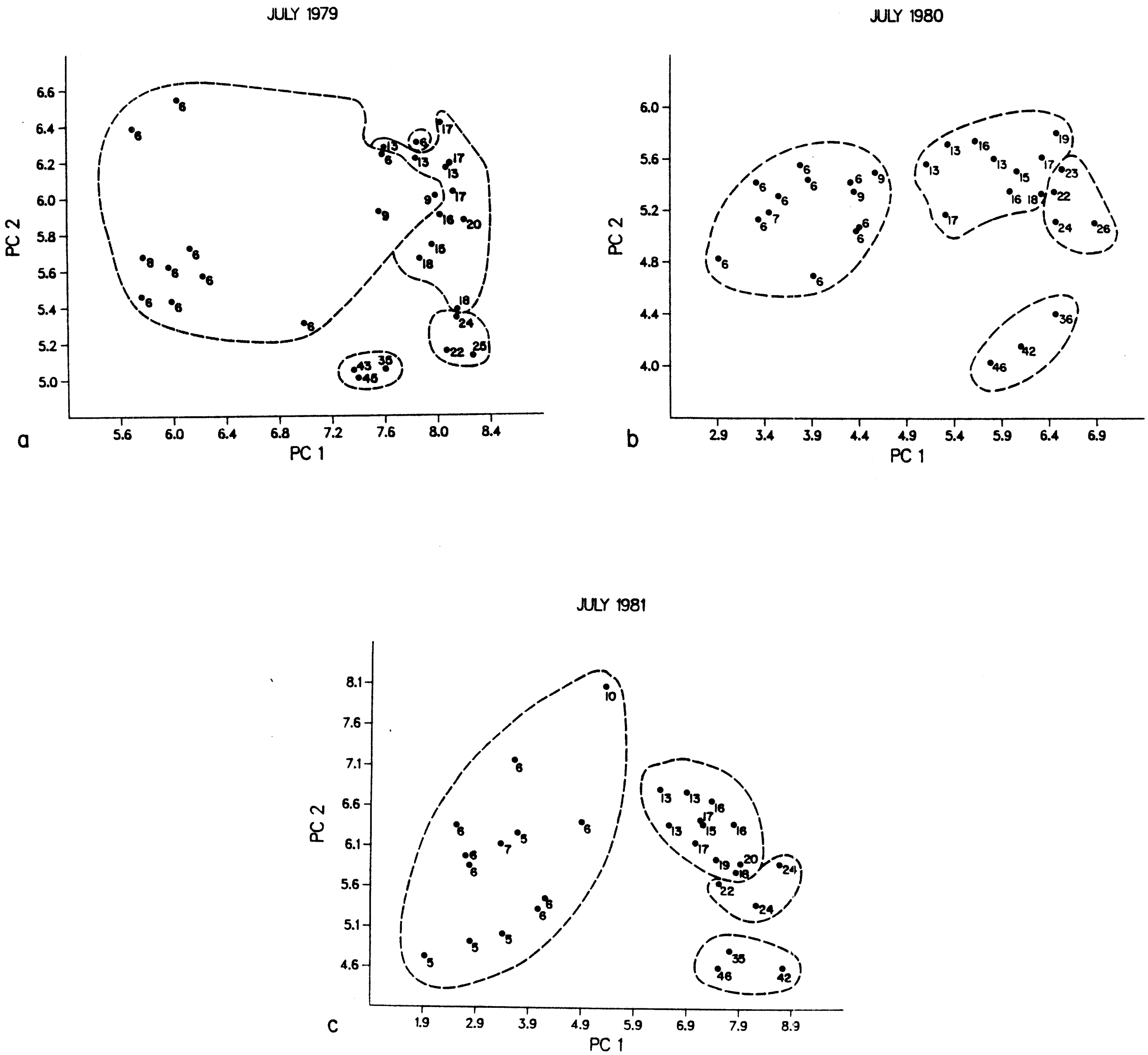


Fig. 23. Principal component ordination of the survey stations sampled on a) 11 July 1979, b) 9 July 1980, and c) 8 July 1981.

assemblages defined by PC1 in July 1980 include an inshore assemblage characterized by relatively high concentrations of copepod nauplii, *Eurytemora affinis* copepodites, *Bosmina longirostris*, minor Cladocera, and *Asplanchna* spp. (Table 2b; Figs. 24b and 25b). The offshore assemblage was characterized by relatively high concentrations of *Cyclops* spp. copepodites, *Diaptomus* spp. copepodites, *Daphnia* spp., and *Limnocalanus macrurus*.

July 1981

There was a strong correlation between PC1 and depth for the July 1981 analysis (Table 2b), which is evident in the ordination of stations by their principal component scores (Fig. 23c). The inshore assemblage was characterized by relatively high concentrations of *Eurytemora affinis* copepodites, *Asplanchna* spp., and *Bosmina longirostris* (Figs. 24c and 25c), while the offshore assemblage was characterized by relatively high concentrations of of *Daphnia* spp., copepod nauplii, *Cyclops* spp. adults, and *Diaptomus* spp. copepodites.

October 1979

The correlation between PC1 and depth was very weak ($|r|=0.34$) for the October 1979 analysis. The ordination plot (Fig. 26a) confirms the weak relationship, with only the deepest stations separating from all others. With the exception of *Bosmina longirostris* (Figs. 27a and 28a), there was little variation in taxa abundances between the inshore and offshore regions. Significant inshore-offshore gradients in *B. longirostris* occurred south of the plant site. To the north, there was little variation in abundance with depth (Fig. 16s). The October 1979 cruise apparently was conducted at the beginning of an upwelling (Fig. 2u) which may have modified spatial gradients

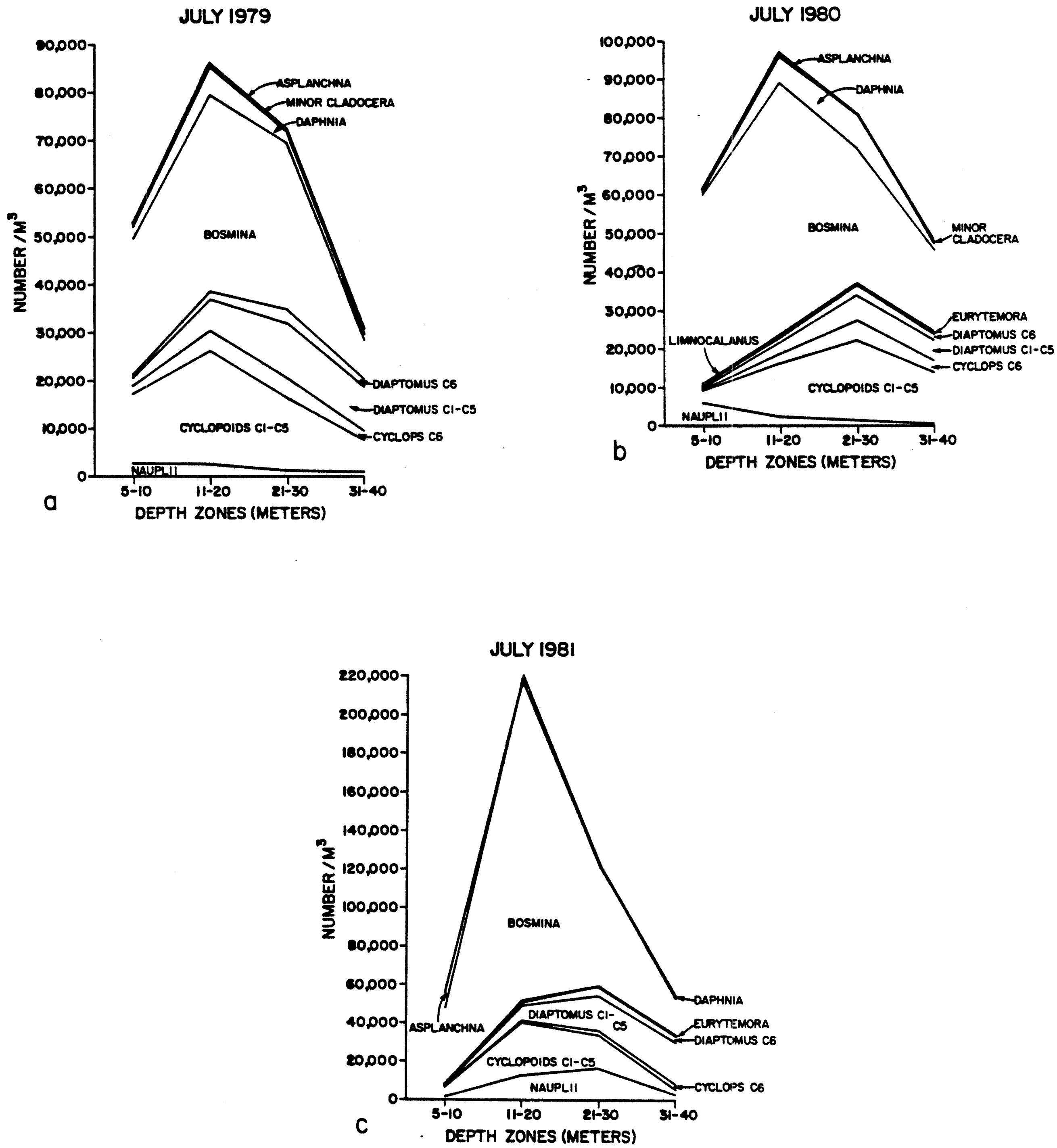


Fig. 24. Mean densities of zooplankton taxa for four depth zones (5-10 m, 10-20 m, 20-30 m, and 30-50 m). a) 11 July 1979, b) 9 July 1980, and c) 8 July 1981.

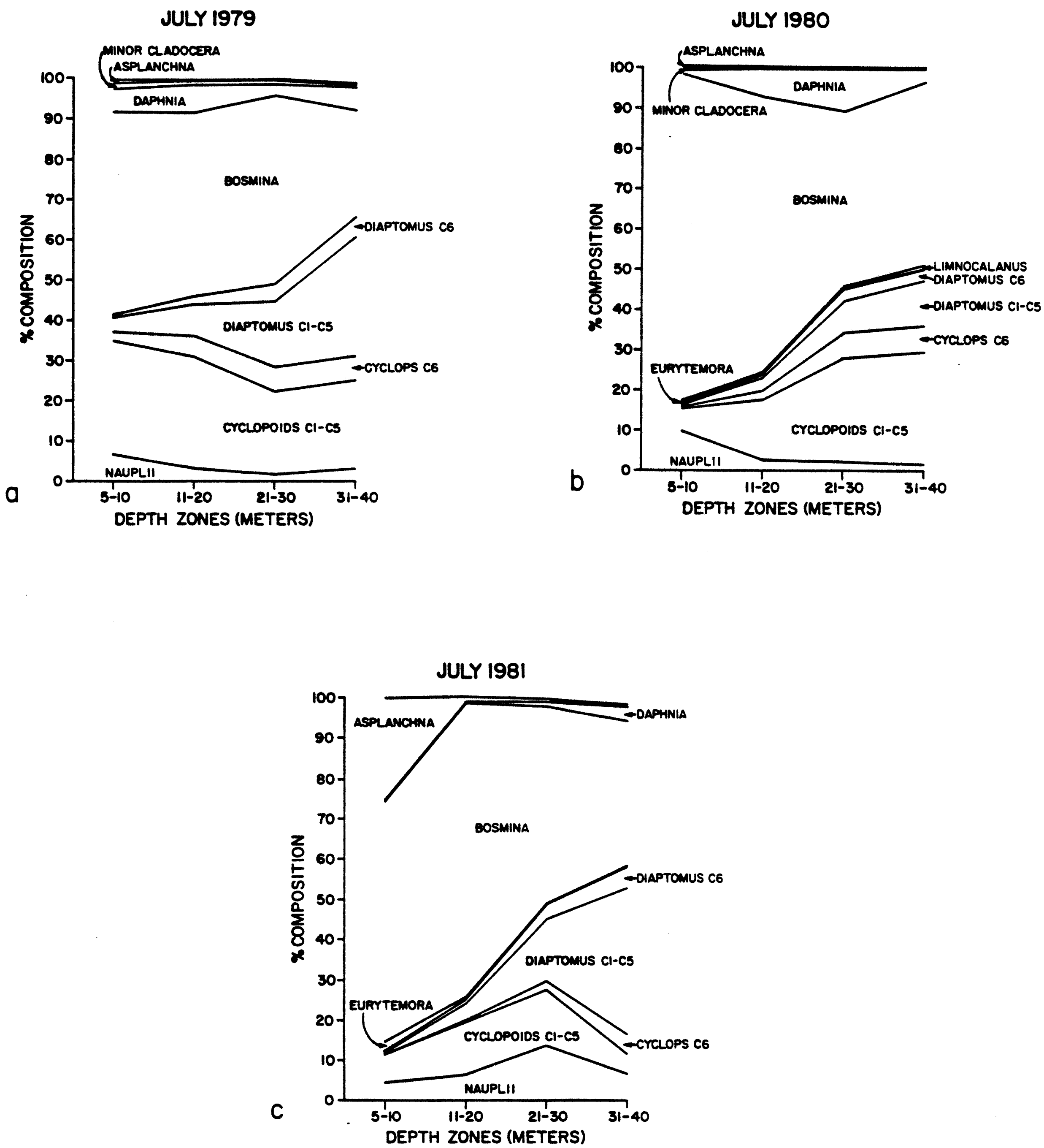


Fig. 25. Mean composition of zooplankton taxa for four depth zones (5-10 m, 10-20 m, 20-30 m, and 30-50 m). a) 11 July 1979, b) 9 July 1980, and c) 8 July 1981.

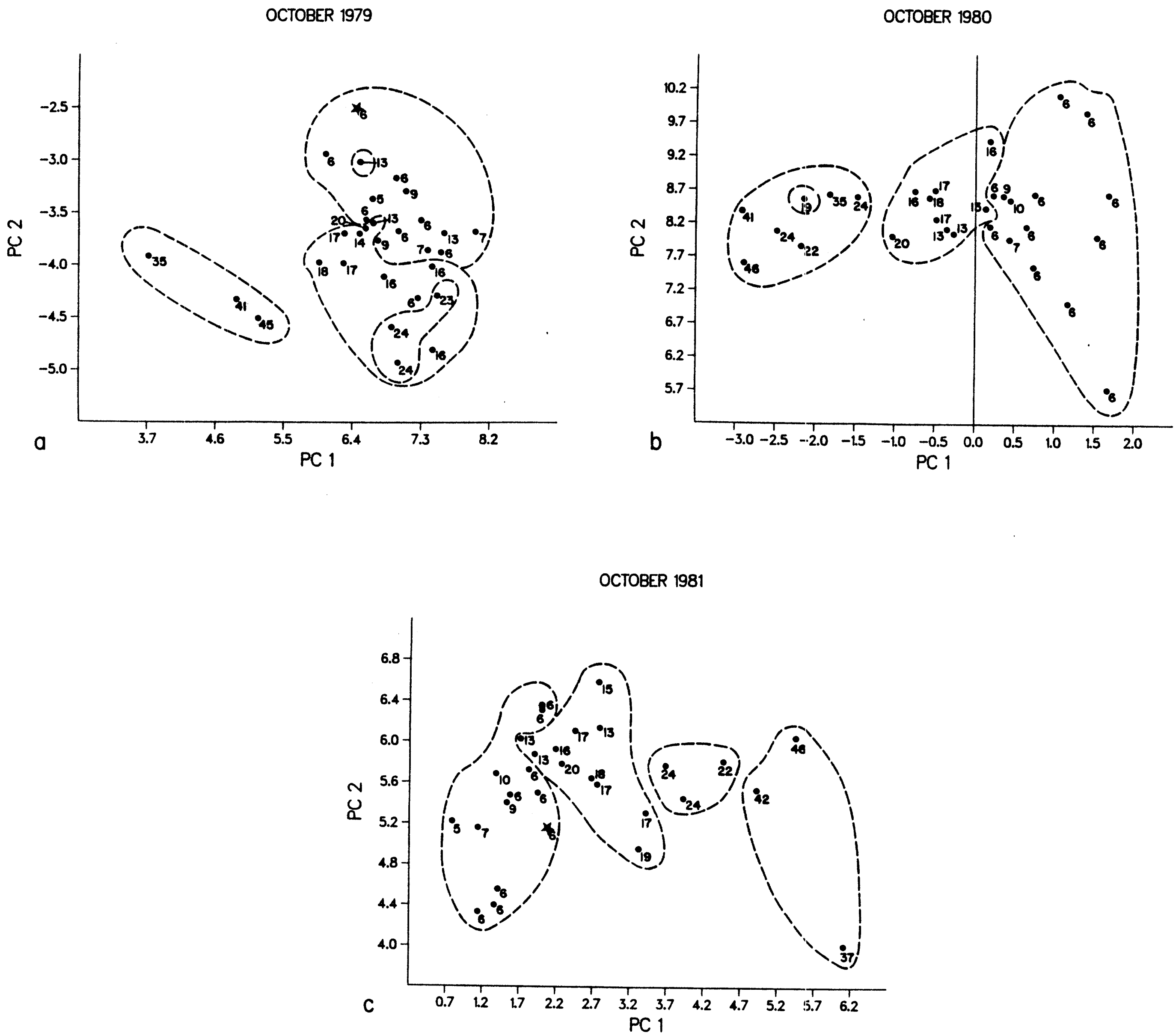


Fig. 26. Principal component ordination of the survey stations sampled on a) 18 October 1979, b) 15 October 1980, and c) 14 October 1981. ★ indicates stations in the thermal plume.

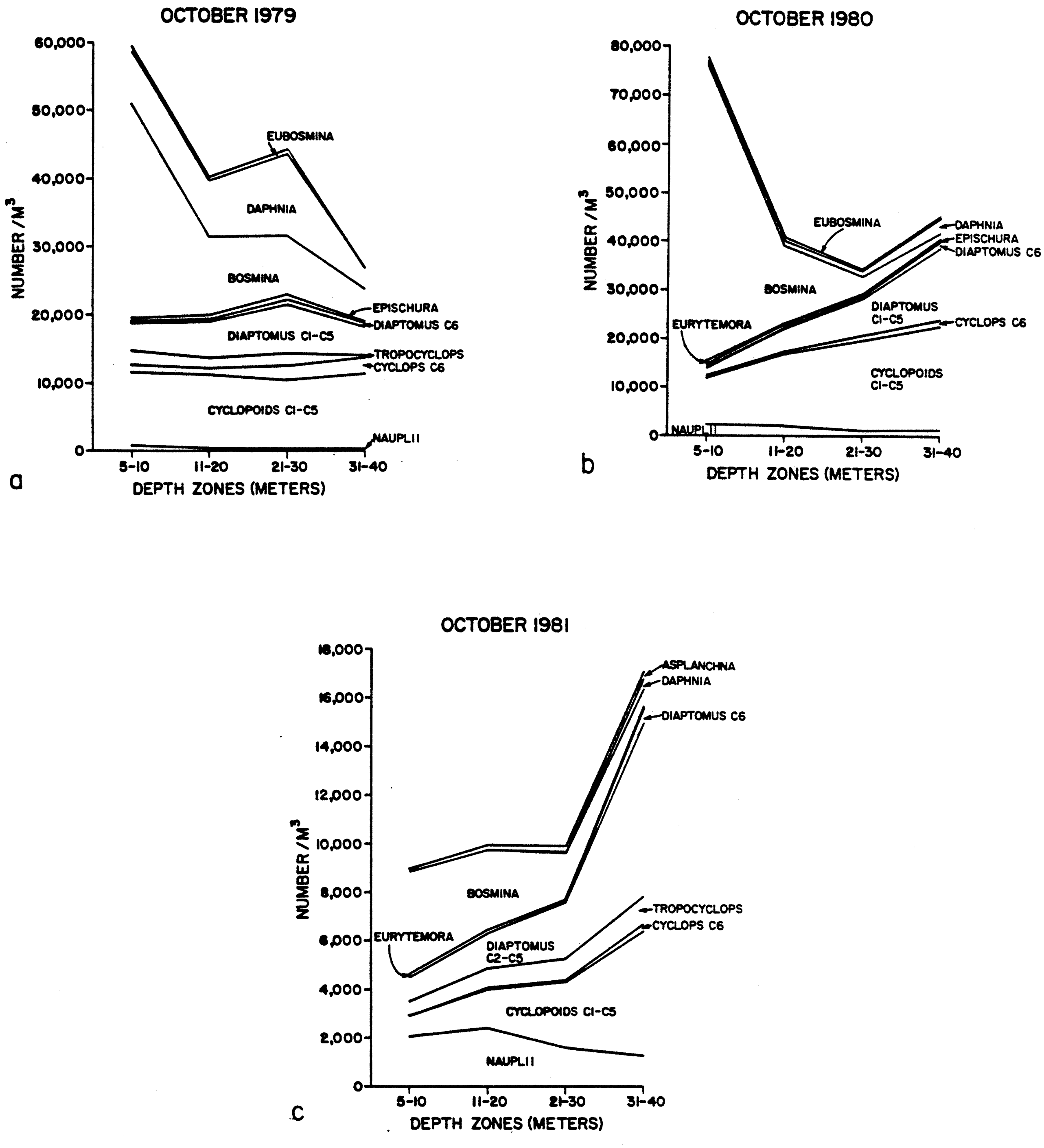


Fig. 27. Mean densities of zooplankton taxa for four depth zones (5-10 m, 10-20 m, 20-30 m, and 30-50 m). a) 18 October 1979, b) 15 October 1980, and c) 14 October 1981.

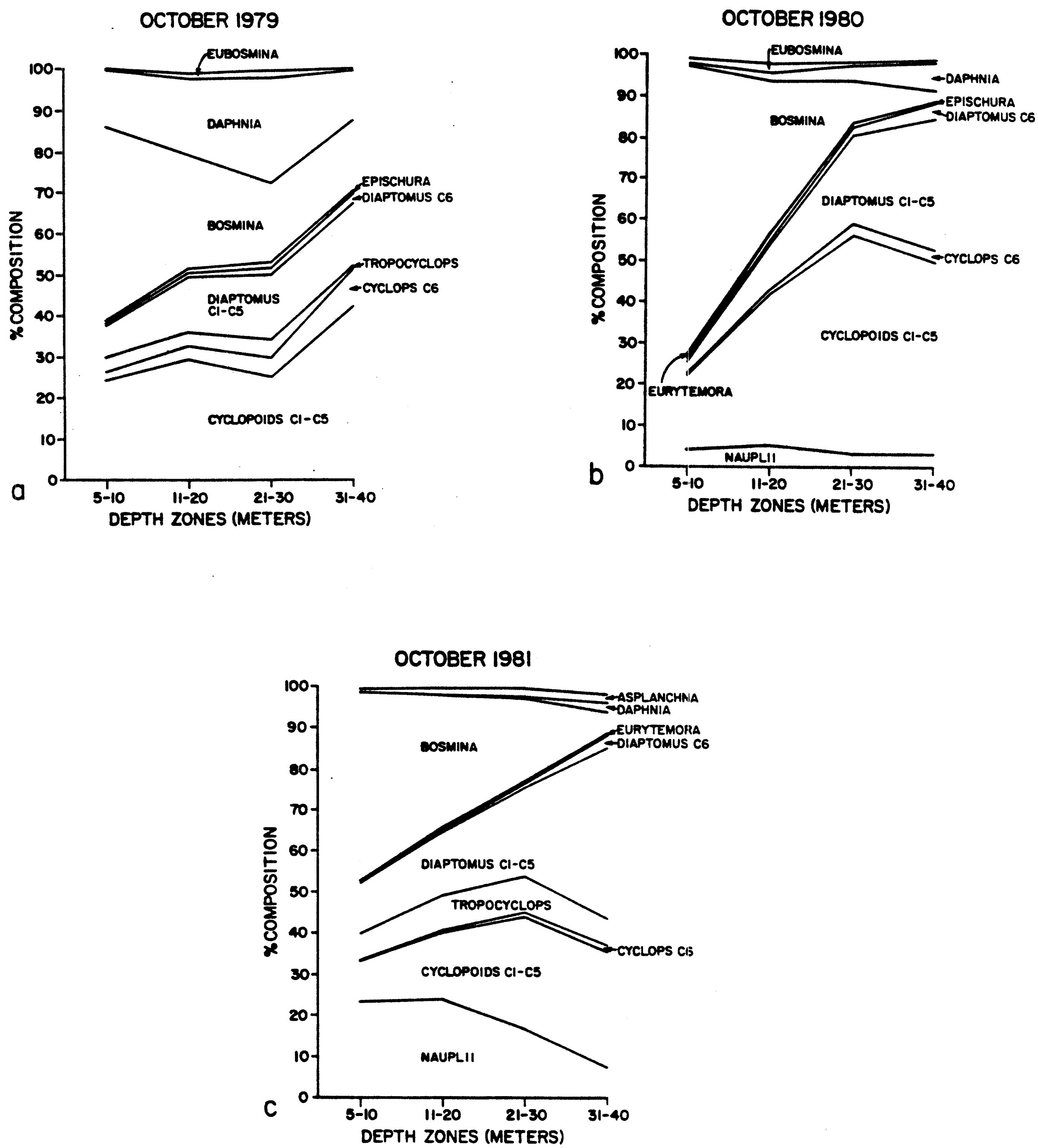


Fig. 28. Mean composition of zooplankton taxa for four depth zones (5-10 m, 10-20 m, 20-30 m, and 30-50 m). a) 18 October 1979, b) 15 October 1980, and c) 14 October 1981.

in zooplankton community structure. There was a strong correlation between PC1 and total zooplankton, indicating that PC1 represents abundance. There was no evidence that zooplankton community structure differed between plume and control stations in the inshore region.

October 1980

Principal component 1 was strongly correlated with depth in October 1980 (Table 2c). A distinct grouping by depth is also evident in the principal component ordination of stations (Fig. 26b). The inshore zooplankton assemblage was characterized by relatively high concentrations of copepod nauplii, *Epischura lacustris*, *Eurytemora affinis*, *Bosmina longirostris*, and *Eubosmina coregoni* (Table 2c and Figs. 27b and 28b). The offshore community was characterized by relatively high concentrations of *Daphnia* spp., immature *Cyclops* spp. copepodites, *Diaptomus* spp. copepodites.

October 1981

Principal component analysis for October 1981 revealed a high correlation between PC1 and depth (Table 2c). The ordination of stations by their principal component scores shows a clustering of stations by depth (Fig. 26c). The inshore assemblage was characterized by relatively high concentrations of copepod nauplii and *Bosmina longirostris*, while the offshore assemblage was characterized by relatively high concentrations of immature *Cyclops* spp. copepodites, immature *Diaptomus* spp. copepodites and *Daphnia* spp. (Table 2c and Figs. 27c and 28c).

Zooplankton Seasonal Mean Densities, by Depth Zone

Zone mean densities by depth zone and by season were calculated to provide a final overview of the spatial and seasonal aspects of zooplankton community structure (Table 4). Total zooplankton generally were most abundant in the middle and inner offshore zone. In the middle depth zone and the two offshore zones, abundances increased from spring to summer and then declined in autumn. However, in the inshore zone, abundances did not decline in autumn and were approximately as high as in summer. Some taxa, such as *Bosmina longirostris*, *Chydorus sphaericus*, and *Eurytemora affinis*, generally attained their highest abundance in the inshore zone and decreased in abundance with increasing station depth. Conversely, taxa such as *Diaptomus sicilis*, *D. ashlandi*, *Limnocalanus macrurus*, and *Daphnia* spp. tended to increase in abundance with increasing station depth. In general, the inshore region was dominated by small-bodied taxa while the offshore region was more strongly dominated by large-bodied taxa. Hypolimnetic taxa, such as *L. macrurus* and *D. sicilis*, were rare in the inshore region during the warmer seasons of the year.

DISCUSSION

The results of the 1979 to 1982 zooplankton lake surveys were similar to those conducted in previous years and reported in Evans (1975) and Evans et al. (1978a, 1980, 1982). As in these studies, zooplankton community structure ranged seasonally from a spring community dominated by calanoid and cyclopoid copepods, to a summer and autumn community dominated by cladocerans and copepods. Furthermore, spatial patterns in community structure remained similar. Depth continued to be the major factor affecting spatial gradients in zooplankton community structure through much of the field season. There

Table 4. Mean seasonal density of zooplankton in each of four depth zones during 1979-1982. Spring = April and May; Summer = June, July, and August; Fall = September and October.

	INSHORE ZONE #/m^3 (5-10 m depth)			MIDDLE ZONE #/m^3 (10-20 m depth)		
	Spring	Summer	Fall	Spring	Summer	Fall
Copepod nauplii	4,408	3,021	1,818	5,074	4,546	1,965
Cyclops spp. C1-C5	103	4,335	4,829	183	14,180	7,028
Cyclops bicuspidatus thomasi C6	122	275	386	128	1,653	450
Cyclops vernalis C6	0	7	22	0	15	21
Paracyclops fimbriatus poppei C1-C6	0	0	0	0	0	0
Mesocyclops edax C1-C6	0	0	0	0	0	0
Eucyclops spp. C1-C6	0	0	0	0	0	0
Tropocyclops prasinus mexicanus C1-C6	2	163	934	1	132	945
Diaptomus spp. C1-C5	641	1,454	2,264	1,301	5,908	4,327
Diaptomus ashlandi C6	474	60	29	656	861	72
Diaptomus minutus C6	81	92	159	129	252	290
Diaptomus oregonensis C6	2	1	15	3	19	91
Diaptomus sicilis C6	67	1	1	231	18	22
Epischura lacustris C1-C6	4	142	431	8	346	508
Eurytemora affinis C1-C6	17	615	398	13	590	205
Limnocalanus macrurus C1-C6	99	5	0	257	14	0
Senecella calanoides C1-C6	0	0	0	0	0	0
Harpacticoids	0	0	0	0	0	0
Bosmina longirostris	196	28,836	26,402	107	59,535	10,860
Eubosmina coregoni	1	59	417	0	57	428
Daphnia retrocurva	1	739	1,659	6	3,115	1,727
Daphnia galeata mendotae	7	65	429	16	198	647
Daphnia longiremis	0	0	0	0	0	0
Ceriodaphnia spp.	0	13	31	0	18	24
Alona spp.	0	0	1	0	0	0
Chydorus sphaericus	8	52	12	4	26	4
Disparalona rostrata	0	0	0	0	0	0
Diaphanosoma spp.	0	1	57	0	3	80
Macrothrix laticornis	1	0	0	0	0	0
Leydigia quadrangularis	0	0	0	0	0	0
Eurycercus lamellatus	0	0	0	0	1	0
Ilyocryptus spp.	0	0	0	0	0	0
Latona setifera	0	0	0	0	0	0
Sida crystallina	0	0	0	0	0	0
Polyphemus pediculus	0	114	12	0	71	7
Holopedium gibberum	0	41	61	0	123	100
Leptodora kindtii	0	3	3	0	11	6
Asplanchna spp.	2	2,446	352	5	947	350
Total Zooplankton	6,236	42,540	40,722	8,122	92,639	30,157

(continued).

Table 4. Concluded.

	INNER OFFSHORE ZONE #/m^3 (20-30 m depth)			OUTER OFFSHORE ZONE #/m^3 (35-45 m depth)		
	Spring	Summer	Fall	Spring	Summer	Fall
Copepod nauplii	5,339	3,729	1,595	3,398	1,738	936
Cyclops spp. C1-C5	592	10,318	7,752	260	6,237	10,170
Cyclops bicuspidatus thomasi C6	199	2,586	988	260	1,996	1,165
Cyclops vernalis C6	2	5	29	0	1	5
Paracyclops fimbriatus poppei C1-C6	0	0	0	0	0	0
Mesocyclops edax C1-C6	0	0	0	0	0	0
Eucyclops spp. C1-C6	0	0	0	0	0	0
Tropocyclops prasinus mexicanus C1-C6	2	170	1,094	5	32	542
Diaptomus spp. C1-C5	3,497	12,977	8,807	1,356	10,956	9,207
Diaptomus ashlandi C6	794	1,686	236	899	1,438	381
Diaptomus minutus C6	170	319	639	161	177	209
Diaptomus oregonensis C6	6	63	170	11	21	155
Diaptomus sicilis C6	304	115	129	276	175	312
Epischura lacustris C1-C6	13	208	479	7	143	229
Eurytemora affinis C1-C6	12	193	74	10	65	22
Limnocalanus macrurus C1-C6	673	117	4	241	221	86
Senecella calanoides C1-C6	0	0	0	0	0	0
Harpacticoids	0	0	0	0	0	0
Bosmina longirostris	43	17,605	3,226	19	10,609	1,747
Eubosmina coregoni	0	107	294	0	23	120
Daphnia retrocurva	3	2,204	1,881	1	1,063	832
Daphnia galeata mendotae	44	535	1,045	6	595	1,076
Daphnia longiremis	0	0	0	0	0	0
Ceriodaphnia spp.	0	9	17	0	0	2
Alona spp.	0	0	0	0	0	0
Chydorus sphaericus	1	24	7	0	2	0
Disparalona rostrata	0	0	0	0	0	0
Diaphanosoma spp.	0	3	100	0	1	3
Macrothrix laticornis	0	0	0	0	0	0
Leydigia quadrangularis	0	0	0	0	0	0
Eurycercus lamellatus	0	0	0	0	0	0
Ilyocryptus spp.	0	0	0	0	0	0
Latona setifera	0	0	0	0	0	0
Sida crystallina	0	0	0	0	0	0
Polyphemus pediculus	0	65	3	0	114	0
Holopedium gibberum	0	86	149	0	64	3
Leptodora kindtii	0	21	12	0	13	12
Asplanchna spp.	8	320	274	1	81	189
Total Zooplankton	11,702	53,465	29,004	6,911	35,765	27,403

was no evidence of spatial alterations in zooplankton community structure in the vicinity of the thermal plume. The thermal plume was relatively small, detectable only within a small region of the survey grid. Surface temperatures generally were elevated by less than 3C°.

As stated in our previous reports (Evans et al. 1978a, 1982) and in Evans (1981), no mechanism appears to exist which could produce detectable and significant alterations in zooplankton community structure in the vicinity of the plume. The power plant utilizes subsurface discharge jets releasing heated water at a high velocity back into the lake. This results in the formation of a plume which is only slightly warmer (< 3 C°) than surrounding surface waters. Consequently, thermal damage to entrained zooplankton is minimized. Furthermore, the plume rapidly cools as it mixes into the lake; temperatures 2 to 3 C° above ambient persist for less than half an hour while temperatures 1.7 C° (and greater) above ambient persist for less than two and a half hours (United States Atomic Energy Commission 1973). These moderate thermal elevations are insufficient to significantly effect zooplankton reproductive or mortality rates.

Another important feature of the power plant's operating characteristics is the rapid dilution of condenser-passed water which occurs over the discharge jets. This not only dissipates thermal energy, but results in dilution of those zooplankton killed during plant passage. Our best estimate of average zooplankton mortality as a consequence of plant passage is approximately 2% (Section 3). Heated discharge water with its small percentage of dead zooplankton is rapidly diluted in the lake to approximately 30% of its original concentration (assuming an in-plant temperature increase of 10 C° and a thermal elevation of 3 C° over the discharge jets). Intense

vertical mixing over the discharge jets prevents this small percentage (30% x 2% = 0.6%) of zooplankton from settling from the water column. Even if these zooplankton were to settle immediately from the water, a 0.6% loss could not be detected. We have determined that the average coefficient of variation between stations in the inshore region is 39% (Evans and Sell 1983). Given this magnitude of variability, we would need to sample over 200 samples in the plume and control regions in order to statistically detect a 10% loss of zooplankton. Since the thermal plume is generally detectable only at 2 stations, the sensitivity of our study design is sufficient to detect differences of 100% or greater between plume and control regions (Evans and Sell 1983).

In September 1976 and June 1977, we conducted a spatially-detailed study of zooplankton distributions in the thermal plume and ambient waters (Evans 1981). Both studies showed that zooplankton populations for the 1-m depth strata occurred in relatively high densities in the thermal plume. These elevated densities were related to the vertical displacement of deeper living zooplankton into the turbulent waters of the 1-m plume. There was no evidence that thermal or mechical stresses associated with plant operation had any detectable effect on zooplankton populations, even in this spatially-detailed study.

One of the most significant observations made during the 1979 to 1982 lake survey study was the increased occurrence of _D. pulicaria_, a cladoceran species which we first identified as _D. pulex_ and _D. schødleri_ (Evans et al. 1982). This species occurred sporadically and in low numbers ($<30/m^3$) during many of the summer and autumn cruises conducted over the last four years (1978-1981) of our study. This cladoceran did not become abundant until

1982 when it was a major summer and autumn component of the offshore Daphnia species assemblage. The appearance of this species over the late 1970s and its subsequent dominance of the summer and autumn Daphnia communities has been attributed to major changes which occurred in the Lake Michigan alewife community (Evans and Jude 1986). The long-term monitoring studies at the Donald C. Cook Plant provided a unique opportunity to investigate the early beginnings of these changes in the Lake Michigan ecosystem (Scavia et al. 1986).

SECTION 2

EVALUATION OF LONG-TERM TRENDS OF THE EFFECTS OF POWER PLANT OPERATION (1975-1982) ON ZOOPLANKTON POPULATIONS

INTRODUCTION

There were two levels of concern regarding the environmental effects of the operation of the Donald C. Cook Nuclear Plant on zooplankton populations. First, power plant operation could produce localized alterations in zooplankton populations in the immediate discharge area. Secondly, power plant operation could affect a wider area and influence a substantial portion of the lake. Such effects are more likely to be subtle in nature and detectable over the long term.

In Section 1, we examined the 1979-1982 field survey data for evidence of gross alterations in zooplankton populations in the vicinity of the plume. Gross alterations were not observed. As was discussed in Section 1, there is no apparent mechanism by which power plant operation could produce biologically significant spatial alterations in zooplankton populations in the immediate vicinity of the plume.

Some evidence for possible trends of long-term change were noted over the fall 1978 to spring 1982 period. Daphnia pulicaria, a relatively large cladoceran and a species which has been eliminated from small ponds by planktivorous fish (Galbraith 1967), was observed for the first time in October and November 1978. By summer and autumn 1982, it was a summer dominant daphnid (Evans 1985, Evans and Jude 1986). The appearance of this species, and its subsequent dominance of the offshore summer Daphnia community

appears to be related to recent declines in alewife populations (Evans and Jude 1986, Scavia et al. 1986).

In this section, we evaluate the preoperational and operational data base for evidence of long-term changes in zooplankton populations which can be attributed to the direct effects of power plant operation. The monitoring program for the Donald C. Cook Nuclear Plant was designed for such an analytical approach spanning several years of preoperational (1970-1974) and operational (1975-1982) monitoring and extending over a large area (250 km^2) of the lake.

HISTORY OF THE SURVEY PROGRAM

The preoperational zooplankton cruises began in April 1969 and terminated in October 1974. Thirty-eight cruises were conducted. Zooplankton were collected at 7 to 46 stations each month and nearly 1,400 samples were examined. Operational cruises began in April 1975, which was the first cruise after Unit 1 went into operation in February 1975. Unit 2 went on line three years later in April 1978. Fifty-eight cruises were conducted during the 1975-1982 period with each cruise consisting of 14 to 30 stations. Over 2,000 samples have been examined from this period. Over fifty species of copepods and cladocerans have been identified, with one or two new species occurrences noted in each of the more recent years of the study. At this point, a review of the sampling program is provided and the subsets of the data used in the statistical analyses specified.

The sampling grid, the collecting techniques, and the counting methods have improved over the years (Table 5). In the early years of the study, relatively few cruises were conducted, but a large number of stations were

Table 5. Summary of the field survey sampling program.

		Preoperational Years						Operational Years							
		69	70	71	72	73	74	75	76	77	78	79	80	81	82
Apr	Number of stations sampled	9		46	46	27	28	30	30	30	30	30	30	30	30
	Net mesh (μ)	282		156	156	156	156	156	156	156	156	156	156	156	156
	Replicates counted per stations	1		1	1	3	2	2	2	2	2	2	2	2	2
May	Number of stations sampled				8	7	14	14	30	14	14	14	14	14	14
	Net mesh (μ)				156	156	156	156	156	156	156	156	156	156	156
	Replicates counted per station				1	3	2	2	2	2	2	2	2	2	2
Jun	Number of stations sampled				8	156	14	14	14	14	14	14	14	14	
	Net mesh (μ)				156	156	156	156	156	156	156	156	156	156	
	Replicates counted per station				1	3	2	2	2	2	2	2	2	2	
Jul	Number of stations sampled		46	46	28	27	30	30	30	30	30	30	30	30	
	Net mesh (μ)		282	156	156	156	156	156	156	156	156	156	156	156	
	Replicates counted per station		1	1	1	3	2	2	2	2	2	2	2	2	
Aug	Number of stations sampled				7	7	14	30	14	14	14	14	14	14	
	Net mesh (μ)				156	156	156	156	156	156	156	156	156	156	
	Replicates counted per station				1	3	2	2	2	2	2	2	2	2	
Sep	Number of stations sampled		46	46	7	7	14	14	14	14	14	14	14	14	
	Net mesh (μ)		282	156	156	156	156	156	156	156	156	158	156	156	
	Replicates counted per station		1	1	1	3	2	2	2	2	2	2	2	2	
Oct	Number of stations sampled				27	27	30	27	26	30	30	30	30	30	
	Net mesh (μ)				156	156	156	156	156	156	156	156	156	156	
	Replicates counted per station				1	3	2	2	2	2	2	2	2	2	
Nov	Number of stations sampled		46	46	7					14	14	14	14	14	
	Net mesh (μ)		282	156	156					156	156	156	156	156	
	Replicates counted per station		1	1	1					2	2	2	2	2	
Dec	Number of stations sampled							14		14					
	Net mesh (μ)							156		156					
	Replicates counted per station							2		2					

sampled. Identifications, particularly for the cyclopoid copepods, were to a low level of taxonomic resolution. Zooplankton have been identified to an increasingly higher level of taxonomic resolution. The mesh size of the nets used in collecting zooplankton, the number of replicate hauls made at each station, and the subsampling techniques also have varied over the years. Since 1974, no substantial changes have been made in methods.

Stations

The number of stations sampled during a cruise has varied from a minimum of 7 during the 1972 and 1973 short survey cruises to a maximum of 46 in the original (1970 to April 1972) major survey grid. Beginning in 1972, short surveys consisting of eight stations were initiated to provide supplemental information on zooplankton population dynamics. At this time, the major survey grid was reduced to 28 stations. Construction of the discharge structures prevented sampling of DC-1 during most of 1972 and 1973. Dredging and the construction of a temporary safe harbor during this time may have produced short-term, local changes in lake currents in what is now the thermal plume region. Since 1974, the number of major and short survey stations has remained unchanged at 30 and 14 respectively except where noted in Table 5. Major surveys were conducted during some short survey months in the early part of the operational study. This occurred in August 1975 and May 1976 when the plant was not operational during the regularly scheduled major survey cruise. Poor weather and hazardous lake conditions prevented sampling at some of the offshore stations during two October cruises (1975, 1976) and prevented November cruises from being conducted in some years (1973-1976). Two

supplementary December cruises (1975, 1977) were conducted during the operational period.

Only data collected during the April, July, and October major survey cruises (27 to 30 stations) were used in preoperational-operational statistical comparisons. Too few stations were sampled during the short survey cruises to justify statistical comparisons between the preoperational and operational periods. Data from both major surveys and short surveys were used to delineate zooplankton succession patterns and long-term trends in the plume region. However, too few stations were sampled in the northern and southern control areas during the short surveys to justify similar preoperational and operational comparisons.

Nets

A number 5 mesh (282 μm) net was used in 1969 and 1970, and a number 10 (156-μm mesh) net was used in 1971 and continues to be used in the operational period. The 1969 and 1970 data were not used in the analyses because of the lack of comparability of these data with data collected using the finer mesh net. In 1979, a study was conducted comparing the filtering efficiencies of #2 (363-μm mesh), #10 (156-μm mesh), and #20 (76-μm mesh) nets. The major conclusion from the study was that the #10-mesh net provided representative estimates of crustacean zooplankton abundances, with the exception of copepod nauplii, which were underestimated by a factor of 8 to 12 (Evans and Sell 1985).

Replicate Samples

A single net haul was made at each station in 1971 and 1972. After 1972, three replicate hauls were made at each station. However, only two of the

three replicate samples generally were counted from 1974 to 1982. The third replicate occasionally was counted when there was an unusual discrepancy between abundance estimates from the first and second replicates.

Subsampling Techniques

Samples collected between 1969 and 1971 were subsampled with a Stempel pipette. Up to fifteen 1-mL subsamples were counted from each sample. A Folsom plankton splitter also was used to subsample some of the 1971 collections. Density estimates were comparable to those obtained with the pipette (Roth 1973). The Folsom plankton splitter has been used routinely since 1971. Sampling characteristics of the Folsom plankton splitter are discussed in Sell and Evans (1982). Sources of variance associated with subsampling and replicate sampling are discussed in Evans and Sell (1983). Methods of use are described in Section 1.

Taxonomy

The level to which zooplankton were identified has varied with the taxon, the year, and the station (Table 6). Most cladocerans were identified to genus beginning in 1970 although *Eubosmina coregoni* and *Bosmina longirostris* were enumerated as Bosminidae until 1972. Species identifications were made (as described in Section 1) at three stations (DC-2, DC-5, and DC-6) in 1972 and 1973 and at an increasing number of stations in 1974. Beginning in 1975, identifications were made to species at all 14 short survey stations and at 22 of the 30 major survey stations (Fig. 1). Zooplankton have been identified to species, where practical, at all stations since 1977.

Adult calanoid copepods and cladocerans were identified to genus at most preoperational stations and to species at most operational stations. Immature

Table 6. Taxonomic resolution of zooplankton counts made between 1971 and 1982. Years in which taxa are counted at all stations (or at all "species" stations since 1973) are shown as solid lines, years in which taxa are counted at only a few stations (i.e., DC2, DC5 and DC6) are shown as dashed lines, and years in which taxa were not counted are blank.

Taxon	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Copepod nauplii	- - -	- - ———	———	———	———	———	———	———	———	———	———	———
Cyclopoid C1-C6	———	———	———	———	———	———	———	———	———	———	———	———
Cyclopoid C1-C5	- - -	- - -	———	———	———	———	———	———	———	———	———	———
Cyclops spp. C1-C5			———	———	———	———	———	———	———	———	———	———
Tropocyclops sp. C1-C5			- - -	———	———	———	———	———	———	———	———	———
Cyclopoid C6												
Cyclops spp. C6	- - -	- - ———	———	———	———	———	———	———	———	———	———	———
Cyclops bicuspidatus thomasi C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Cyclops vernalis C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Tropocyclops prasinus mexicanus C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
all other cyclopoid species	- - -	- - -	———	———	———	———	———	———	———	———	———	———
Calanoid C1-C6	———	———	———	———	———	———	———	———	———	———	———	———
Calanoid C1-C5	———	———	———	———	———	———	———	———	———	———	———	———
Diaptomus spp. C1-C5			———	———	———	———	———	———	———	———	———	———
Epischura sp. C1-C5			———	———	———	———	———	———	———	———	———	———
Eurytemora sp. C1-C5			———	———	———	———	———	———	———	———	———	———
Limnocalanus sp. C1-C5			———	———	———	———	———	———	———	———	———	———
Calanoid C6	- - -	- - ———	———	———	———	———	———	———	———	———	———	———
Diaptomus spp. C6	- - -	- - ———	———	———	———	———	———	———	———	———	———	———
Diaptomus ashlandi C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Diaptomus minutus C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Diaptomus oregonensis C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Diaptomus sicilis C6	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Epischura lacustris C6	- - -	- - -	———	———	———	———	———	———	———	———	———	———
Eurytemora affinis C6	- - -	- - -	———	———	———	———	———	———	———	———	———	———
Limnocalanus macrurus C6	- - -	- - -	———	———	———	———	———	———	———	———	———	———
all other calanoid species	- - -	- - -	———	———	———	———	———	———	———	———	———	———
Harpacticoid C1-C6	———	———	———	———	———	———	———	———	———	———	———	———
Bryocamptus spp. C1-C5	———	———	———	———	———	———	———	———	———	———	———	———
Bryocamptus spp. C6	———	———	———	———	———	———	———	———	———	———	———	———
Canthocamptus spp. C1-C6	———	———	———	———	———	———	———	———	———	———	———	———
Canthocamptus spp. C6	———	———	———	———	———	———	———	———	———	———	———	———
Cladocerans	———	———	———	———	———	———	———	———	———	———	———	———
Bosminidae	———	———	———	———	———	———	———	———	———	———	———	———
Bosmina longirostris	———	———	———	———	———	———	———	———	———	———	———	———
Eubosmina coregoni	- - -	- - ———	———	———	———	———	———	———	———	———	———	———
Daphnia spp.	- - -	- - ———	———	———	———	———	———	———	———	———	———	———
Daphnia retrocurva	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Daphnia galeata mendota	- - -	- - -	- - -	———	———	———	———	———	———	———	———	———
Daphnia longiremus								———	———	———	———	———
Daphnia pulicaria	———	———	———	———	———	———	———	———	———	———	———	———
Alona spp.	———	———	———	———	———	———	———	———	———	———	———	———
Disparalona spp.*	———	———	———	———	———	———	———	———	———	———	———	———
Diaphanosoma spp.	———	———	———	———	———	———	———	———	———	———	———	———
Ceriodaphnia spp.	———	———	———	———	———	———	———	———	———	———	———	———
all other cladoceran species	———	———	———	———	———	———	———	———	———	———	———	———
Asplanchna spp.	———	———	———	———	———	———	———	———	———	———	———	———

*Designated *Alonella* spp. before 1976

calanoid copepodites were combined as a group until 1973. After that time they were identified to genus. Cyclopoid copepods generally were combined as a group until 1973, although immatures and adults were distinguished at three species stations (DC-2, DC-5, and DC-6) beginning in 1972. Since April 1973, adult Cyclops spp. were separated from immatures at all stations. Tropocyclops prasinus mexicanus adults and immature copepodites were not distinquished until 1974. Immature and adult harpacticoid copepods were not distinguished until 1974. Beginning in 1974, cyclopoid and harpacticoid copepods were identified to the same level of taxonomic resolution as calanoid copepods.

Copepod nauplii were combined into a single category. They were not enumerated in 1969 and 1970 when the 282-μm mesh net was used. A 156-μm net was used after 1971. However, nauplii densities were underestimated since many of the smaller cyclopoid nauplii escape through this even finer mesh net (Evans and Sell 1985). Studies utilizing collections made in 1979 with a 76-μm mesh net suggest that this loss may exceed a factor of 8. Nauplii were not routinely counted at all stations until 1972.

The only rotifer enumerated was Asplanchna, which was identified to genus level. Although other rotifer species occurred in the samples, their small size precluded their being sampled quantitatively by the 156-μm aperture net.

METHODS

Analytical Design of the Survey Grid

Examinations of the preoperational and operational data, by survey cruise, have shown significant spatial variations in zooplankton abundance. The greatest spatial variations observed during most cruises were associated

with depth or distance from shore (Section 1; Evans et al. 1980, 1982). Subdivison of the survey grid into four depth-related regions (Fig. 29) is supported by the results of principal component analyses and graphical analyses of zooplankton density-depth trends. These regions are designated the inshore (5- to 10-m depth contour), the middle (10- to 20-m depth contour), the inner offshore (20- to 30-m depth contour), and the outer offshore (30- to approximately 45-m depth contour) regions.

Although zooplankton varied in abundance along transects parallel to shore, this variation was not consistent from month to month and was probably associated with transient zooplankton patchiness. We could not further subdivide the survey grid on the basis of consistently observed alongshore patterns in zooplankton abundance. Further subdivisions were based on the location of the thermally detectable plume. Generally, the plume was detected only within 1.6 km of the discharge jets (DC-1) and while it generally flowed parallel to shore, it sometimes had a strong offshore component (Section 1; Indiana & Michigan Electric Power Company 1976). The inshore and middle depth regions were subdivided into plume zones, extending 1.6 km north and south of the discharge site, and into northern and southern control zones. The small number of stations in the two offshore zones precluded further subdivision of these areas (Fig. 29).

Temporal succession patterns of selected, numerically dominant taxa in the inshore plume zone (Zone 2), the middle plume zone (Zone 5), and the inner and outer offshore zones (Zones 7 and 8) were examined in time series graphs. These graphs facilitate examination of zooplankton temporal succession patterns for evidence of long-term population trends. These graphs also

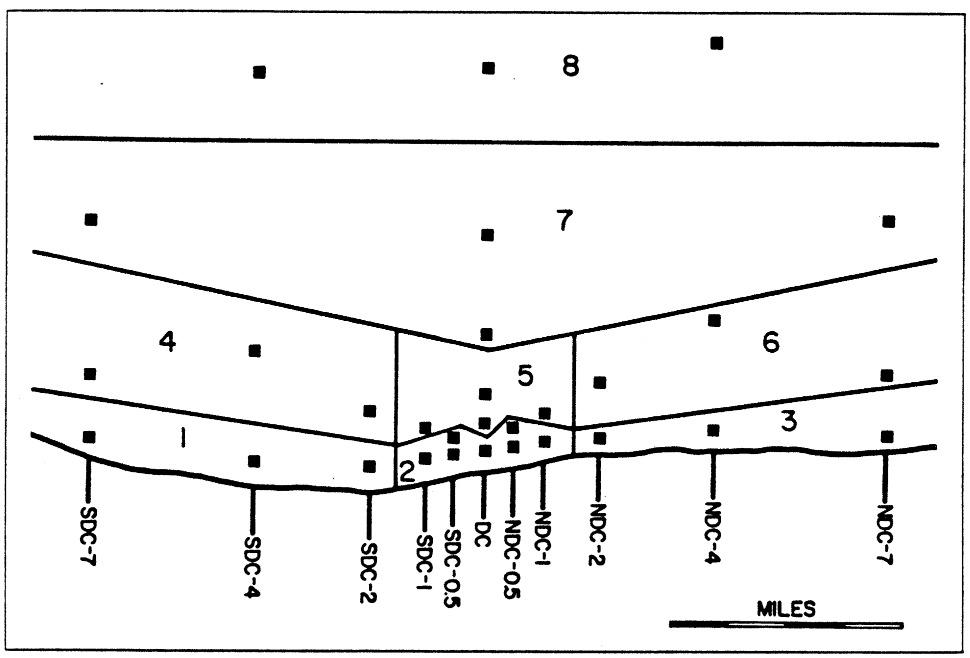


Fig. 29. Thirty station major survey grid divided into the eight zones used in the preoperational and operational comparisons.

provide information on the magnitude of temporal variations in zooplankton abundance both from month-to-month and from year-to-year.

Statistical analyses comparing zooplankton abundances between the preoperational and operational periods were the major tests used in evaluating plant effects. These analyses utilized the major survey data and compared zooplankton abundances by zone and by month between the preoperational and operational periods.

Statistical Test Design

The data set was stratified into preoperational and operational blocks and station density estimates were compared by using the Mann-Whitney U test (Siegel 1956, Conover 1971). These comparisons were made separately for each month and zone in order to reduce spatial and temporal variability which was irrelevant to our investigation of power plant impact. The Mann-Whitney U test is a non-parametric procedure based on the ordered ranks of the data. A two-sided test was used to evaluate the zone densities before and during plant operation. The power efficiency of the Mann-Whitney U test is at least 86% that of the parametric t-tests and is generally higher when the data are not normally distributed (Conover 1971).

The assumptions underlying the Mann-Whitney U tests appear to have been met. The samples were independent and drawn randomly from the zooplankton populations at each station. The density estimates represented continuous random variables and the measurement scale was at least ordinal. The third assumption is that control and experimental populations differed only in the location of their mean.

Parametric tests for detecting differences between populations, such as Student's t-tests and the analysis of variance, were not used. Their assumption of normality could not be met by all the data. Both $\log_{10}(\#/m^3 + 1)$ and square root transformation of the density estimate failed in many cases to result in normality.

Calculations were performed on the AMDAHL 470V/8 computer at the University of Michigan using the TWOSAMPLE program incorporated into MIDAS. Zone densities differing at the 95% confidence level were considered statistically significant.

Zooplankton Taxa Tested

Although over fifty species of zooplankton taxa have been identified in the survey area, it was neither practical nor necessary to analyze the distributions of all taxa. We used the guidelines set by the Michigan Department of Natural Resources in selecting taxa to be considered in the evaluation of plant operation on the "maintenance of a balanced indigenous population in the discharge area." The department recommended that the following categories of zooplankton be considered for preoperational and operational comparisons:

(1) those taxa which account for 10% of the zooplankton by weight or by numbers in each of the four seasons
(2) threatened or unique species
(3) pollution-tolerant species
(4) temperature-sensitive species
(5) nuisance-potential species
(6) species of significance to public health

(7) species indicative of certain water quality or environmental conditions

(8) species of historical significance. They further recommended that all developmental stages and physiological processes be evaluated (adults, juveniles, growth, feeding, etc.).

The numerically dominant taxa in the spring, summer, and autumn, and winter have been identified (Section 1) as *Cyclops* spp., *Diaptomus* spp., *Bosmina longirostris*, *Eubosmina coregoni*, and *Daphnia* spp. Potentially pollution tolerant species include *Cyclops bicuspidatus thomasi* and *Bosmina longirostris* (Gannon and Stemberger 1978). A number of other species thrive in shallow, eutrophic waters (*C. vernalis*, *Eurycercus lamellatus*, *Alona* spp., and *Chydorus sphaericus*). However, they generally are rare in the plankton in the survey area (Table 4). The error associated with estimating concentrations of these taxa is so large that only extremely large differences in abundances could be detected with the four-year operational data base. Visual comparisons of these preoperational and operational data did not reveal large differences, so the data were not further analyzed.

Temperature sensitive zooplankton include hypolimnetic species such as *Limnocalanus macrurus*, *Daphnia longiremis*, and *Diaptomus sicilis* (Wells 1960). Statistical analyses were performed only for *L. macrurus* in April: this taxon was not sufficiently abundant over the survey grid in July and October to merit further statistical analyses. The preoperational data base was not adequate for *D. longiremis* and *D. sicilis* since these taxa were identified to species at only a limited number of stations. Furthermore, *D. longiremis* was only rarely collected in the study area.

All zooplankton are important in energy transfer: the quantitative importance of each species is unknown. Thus, the numerically dominant herbivores (*Diaptomus* spp., *Bosmina* sp., *Daphnia* spp.) were used in the analyses. The only omnivores sufficiently abundant for statistical analyses were *Limnocalanus macrurus* and *Cyclops* species. Carnivorous zooplankton such as *Polyphemus pediculus*, *Leptodora kindtii*, and adult *Epischura lacustris* were not sufficiently abundant to merit statistical analysis. *Asplanchna* spp., a carnivorous rotifer, was occasionally abundant and preoperational and operational comparisons were made for this genus in selected months.

There are no zooplankton in categories 2, 5, 6, and 8. The monitoring program was not designed to measure zooplankton physiological processes such as feeding and growth. To a limited extent, copepod growth is considered by investigation of the three developmental categories (nauplii, immature copepodites, and adults) of the various copepod taxa.

Comparisons were made at several taxonomic levels. Order and suborder classifications (i.e. Cladocera, Cyclopoida, Calanoida) were used in order to utilize the largest possible preoperational data set (1971-1974) for making preoperational and operational comparisons. Comparisons at the genus or species level and for immature and adult copepodites could be made only with a two or three year subset of the preoperational data base.

RESULTS

Temporal Abundance Patterns of Zooplankton in Zones 2, 5, 7, and 8 (1971-1982)

The temporal abundance patterns of the 10 most common zooplankton taxa in zones 2 (inner plume zone), 5 (outer plume zone), 7 (inner offshore zone), and

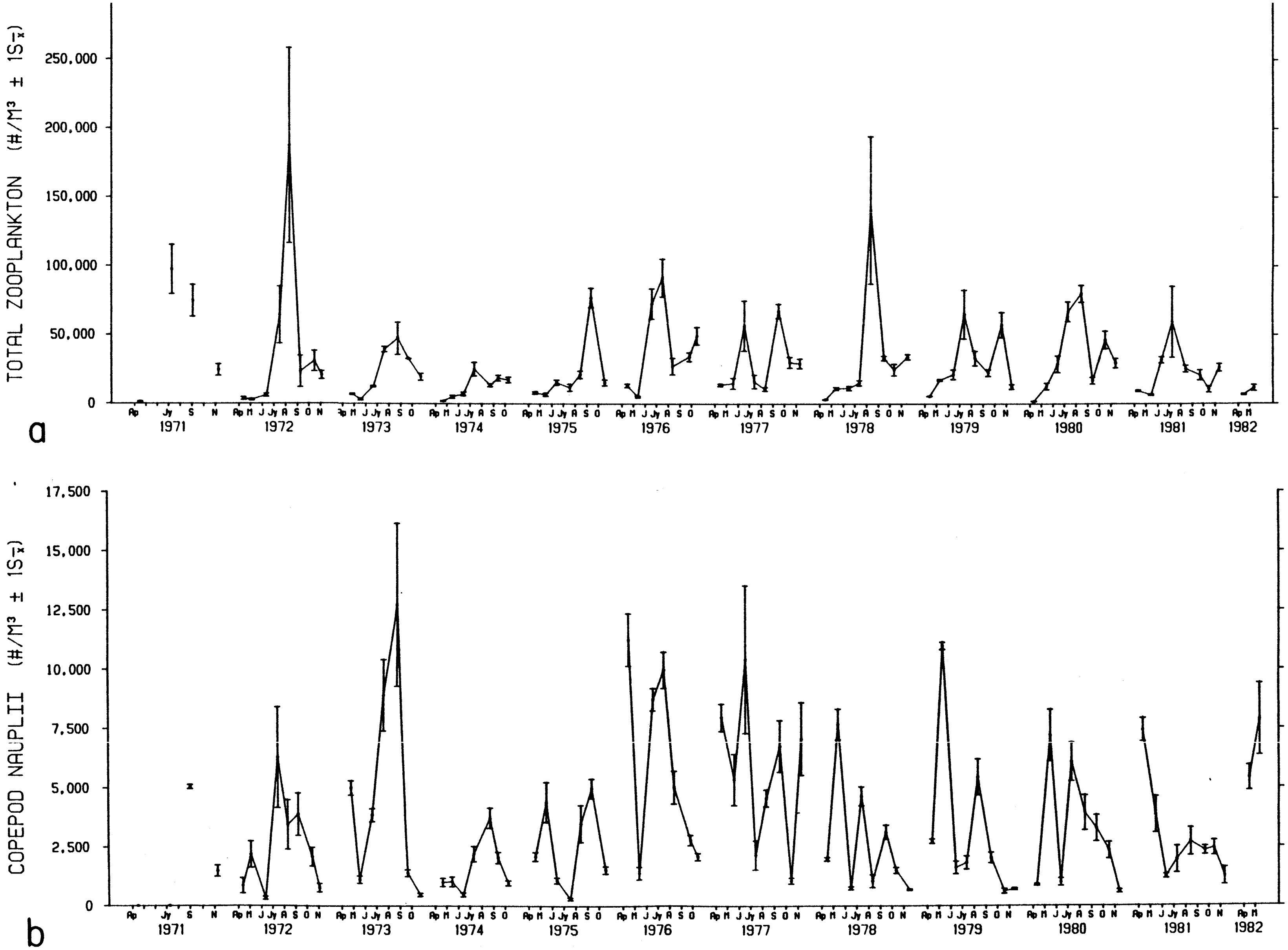


Fig. 30. The monthly abundance of zooplankton in the inshore plume zone (zone 2) between 1970 and 1982. a) Total zooplankton, b) copepod nauplii,

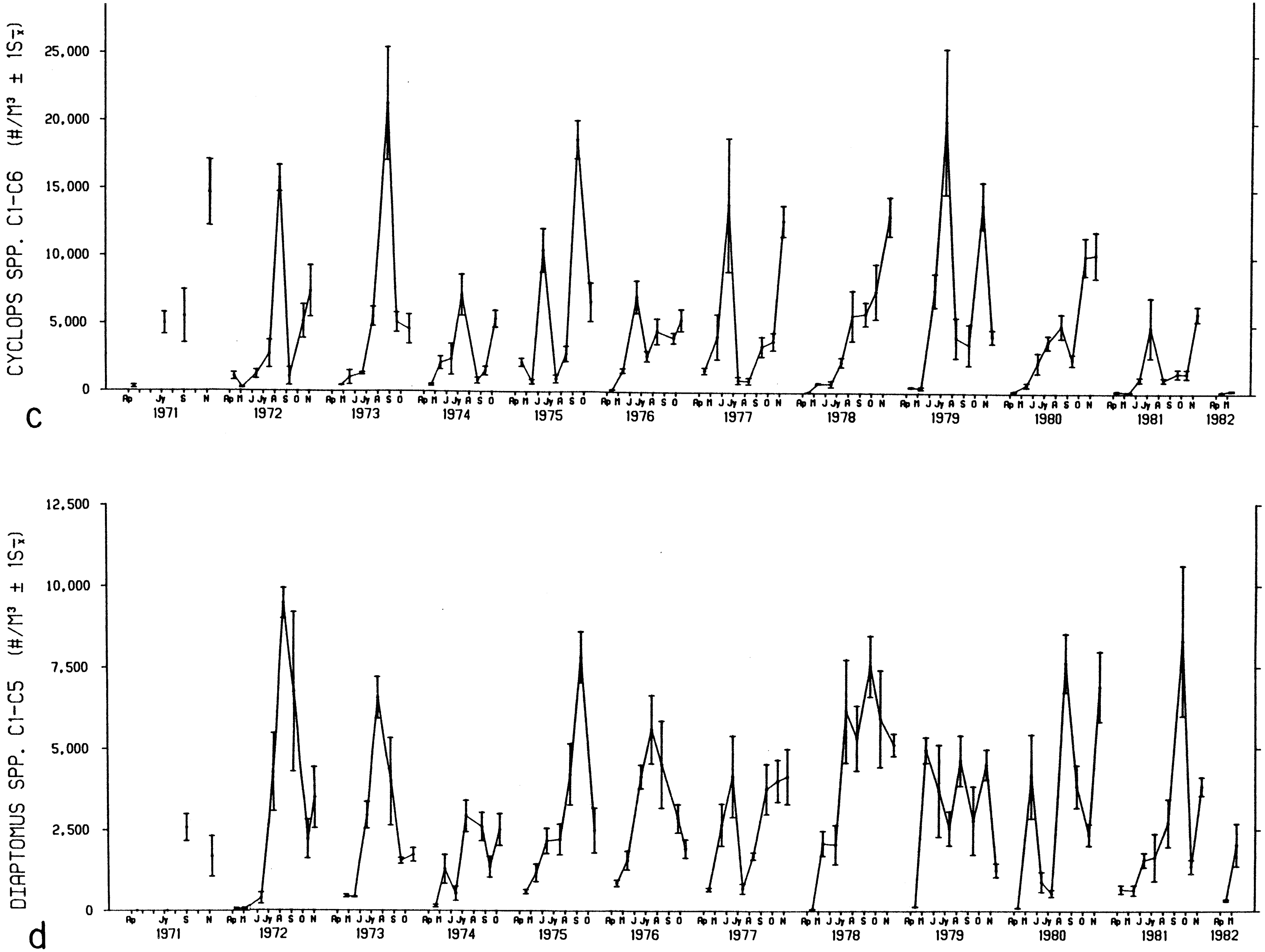


Fig. 30. Continued. c) cyclopoid copepods C1-C6, d) *Diaptomus* spp. C1-C5,

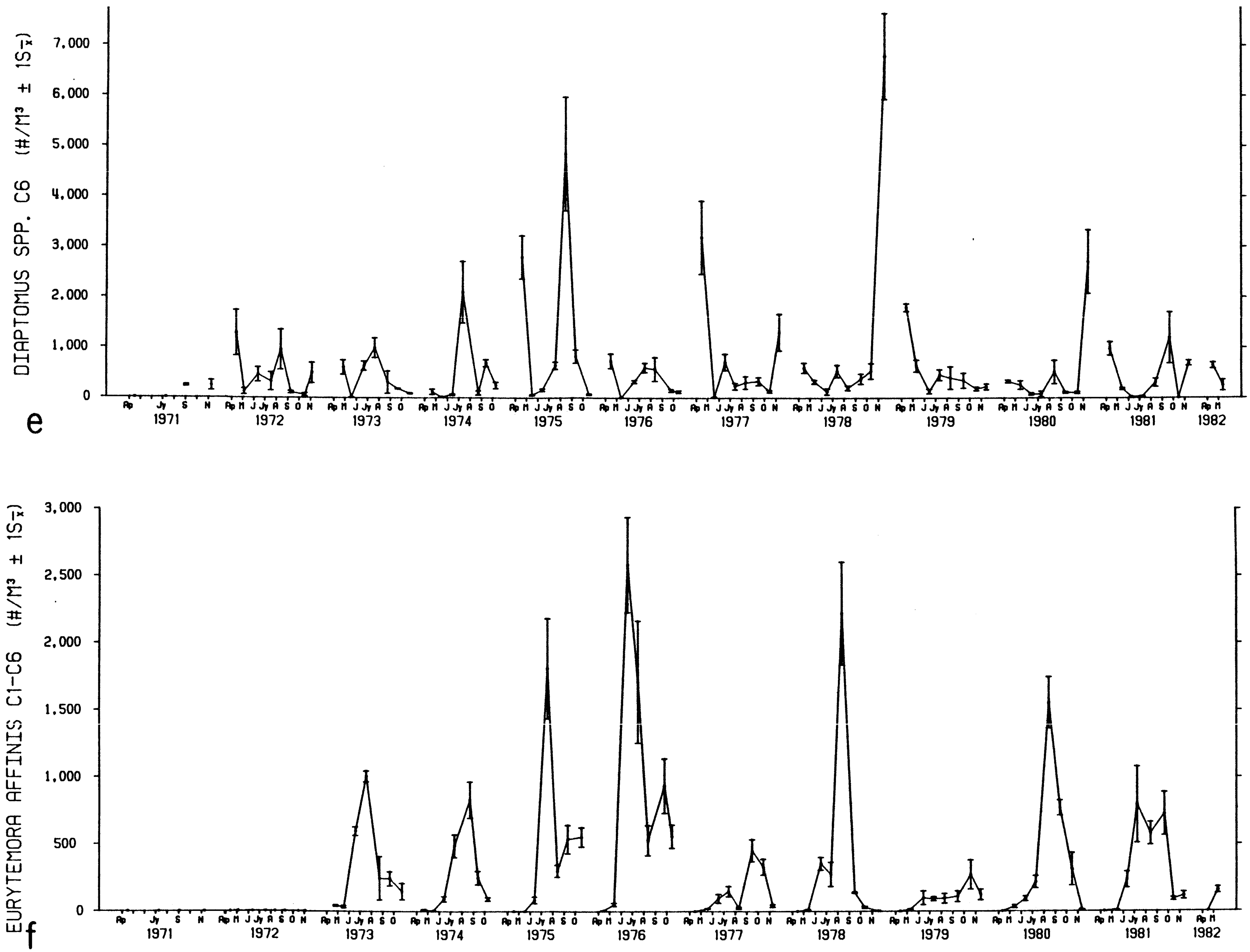


Fig. 30. Continued. e) Diaptomus spp. C6, f) Eurytmora affinis C1-C6,

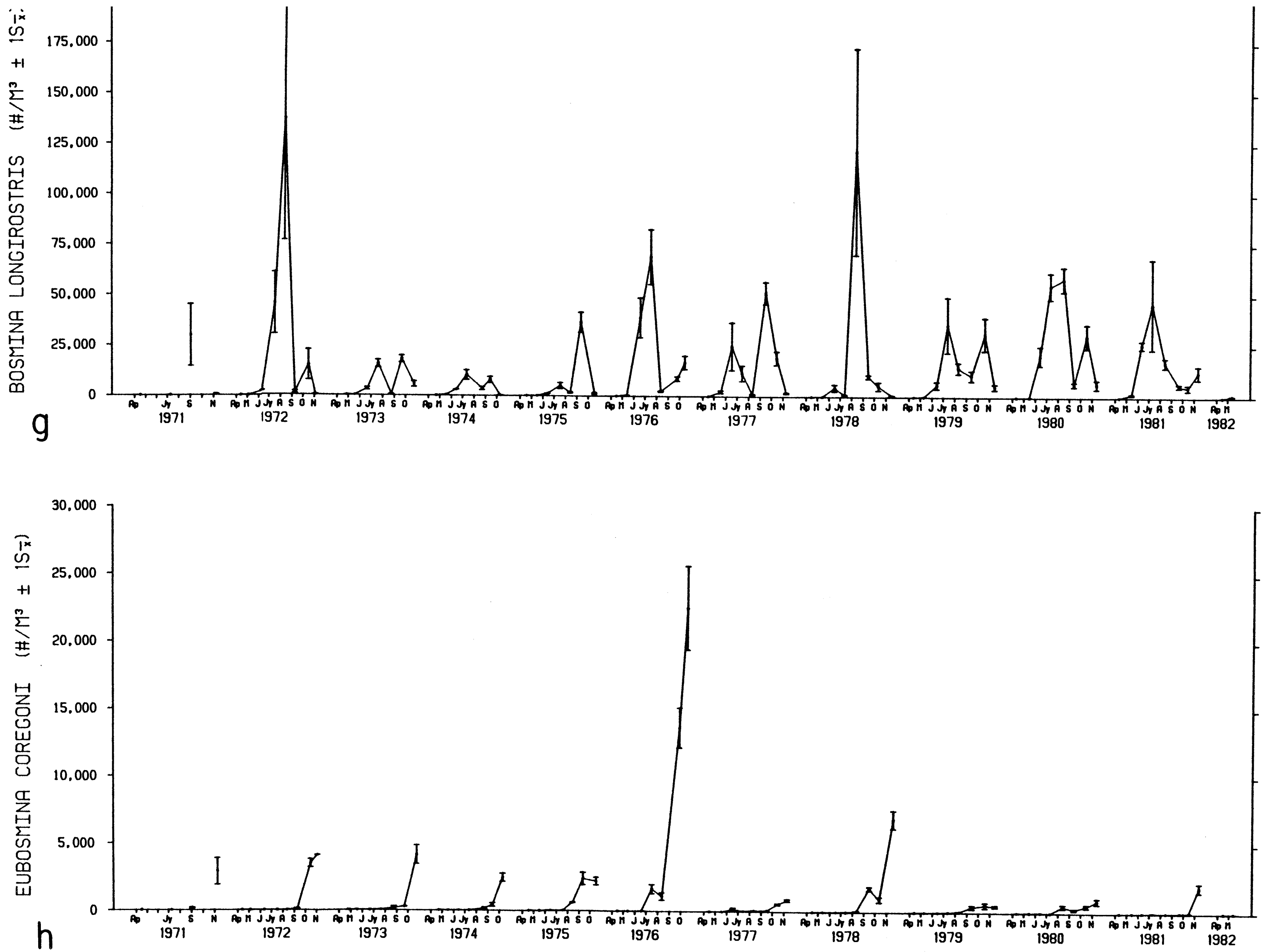


Fig. 30. Continued. g) Bosmina longirostris, h) Eubosmina coregoni,

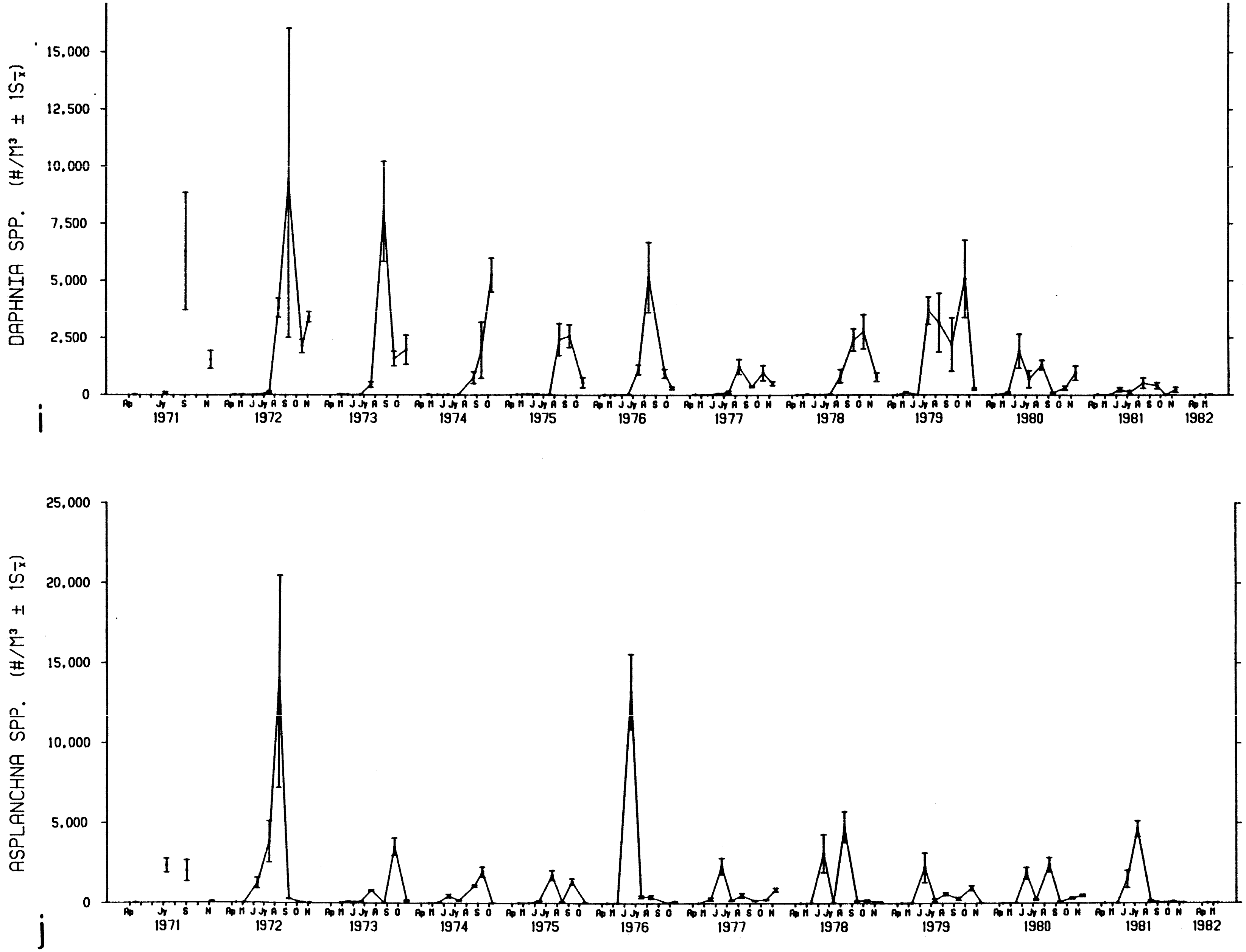


Fig. 30. Concluded. i) <u>Daphnia</u> spp., j) <u>Asplanchna</u> spp.

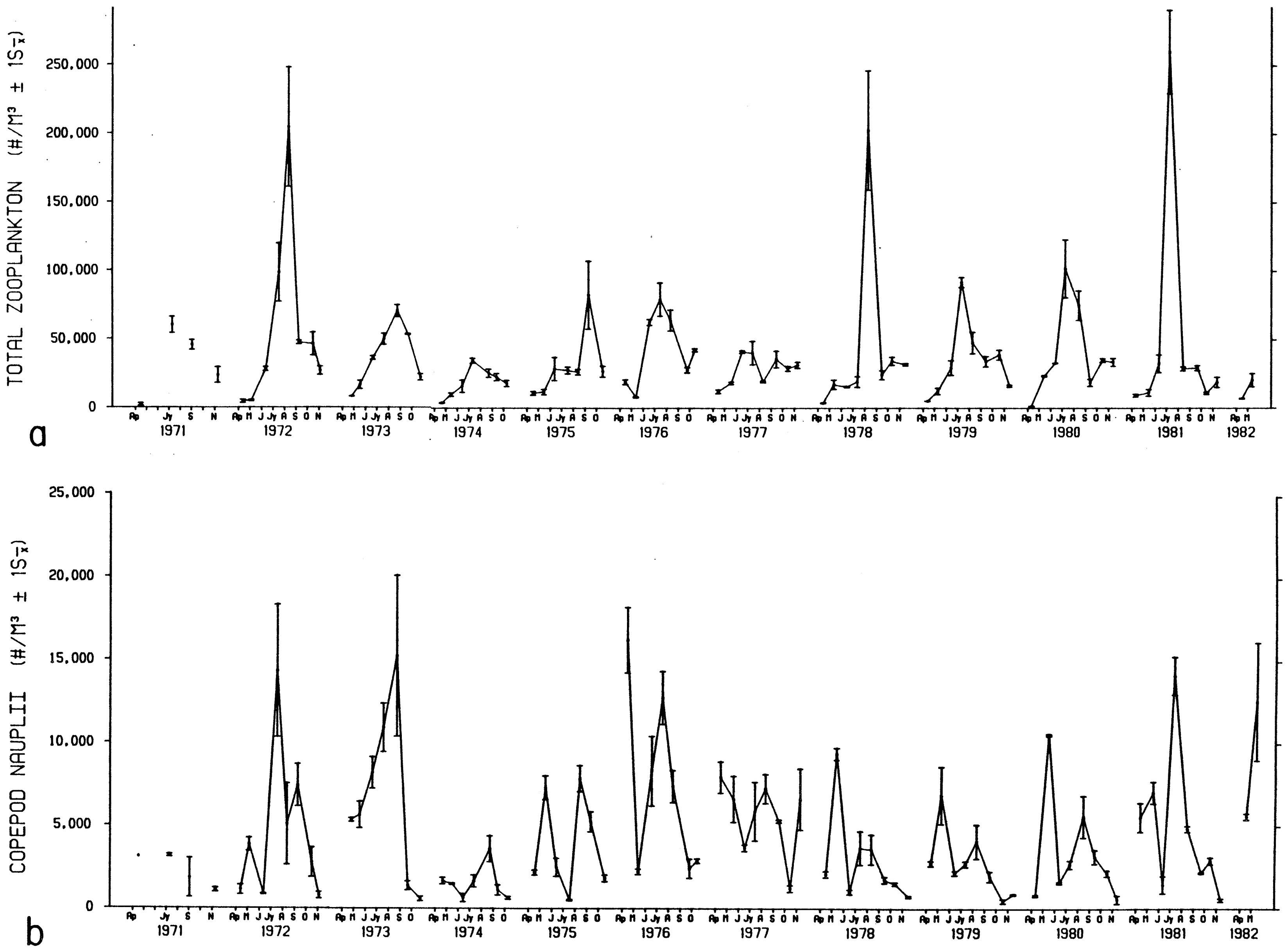


Fig. 31. The monthly abundance of zooplankton in the middle shore zone (zone 5) between 1970 and 1982. a) Total zooplankton, b) copepod nauplii,

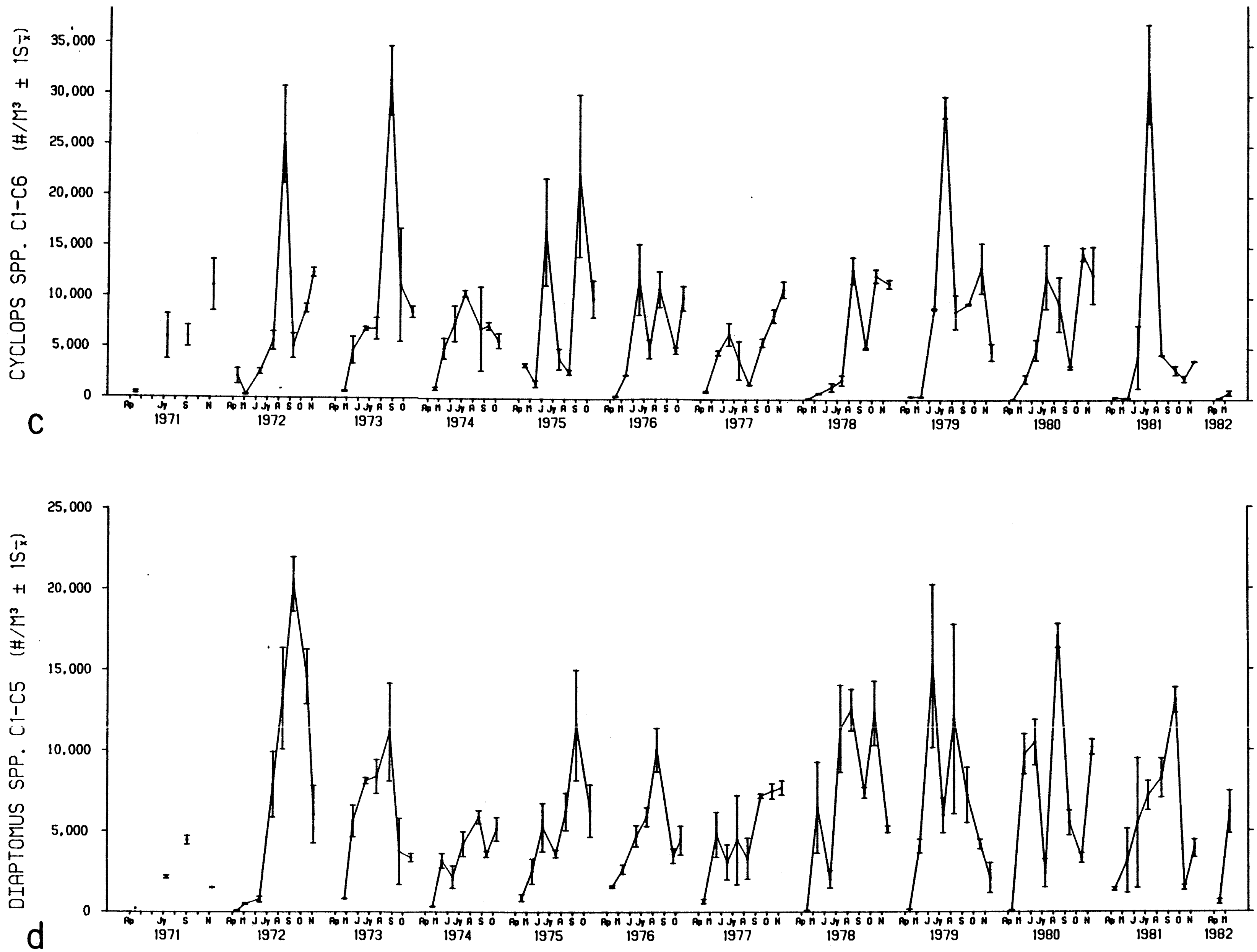


Fig. 31. Continued. c) cyclopoid copepods C1-C6, d) *Diaptomus* spp. C1-C5,

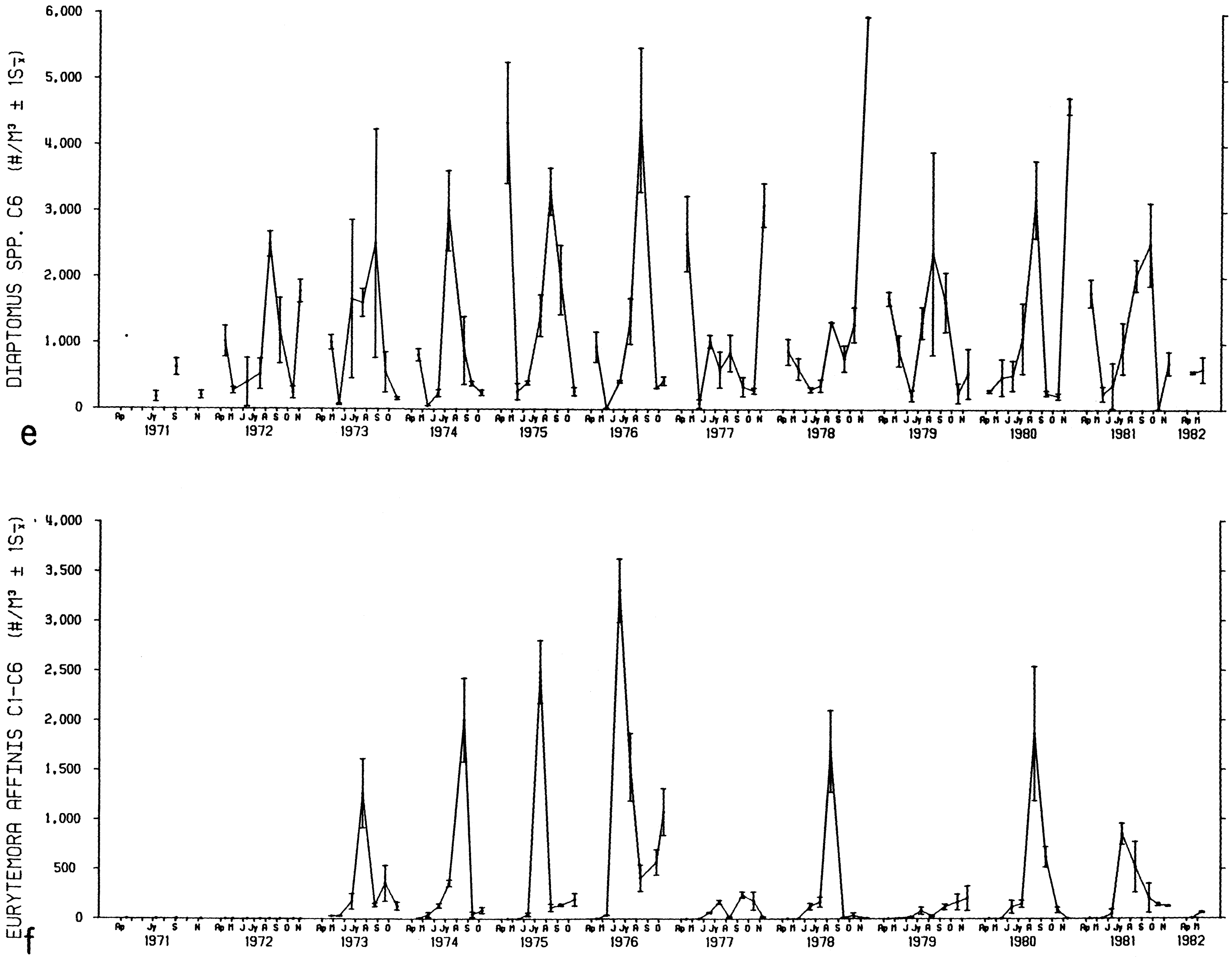
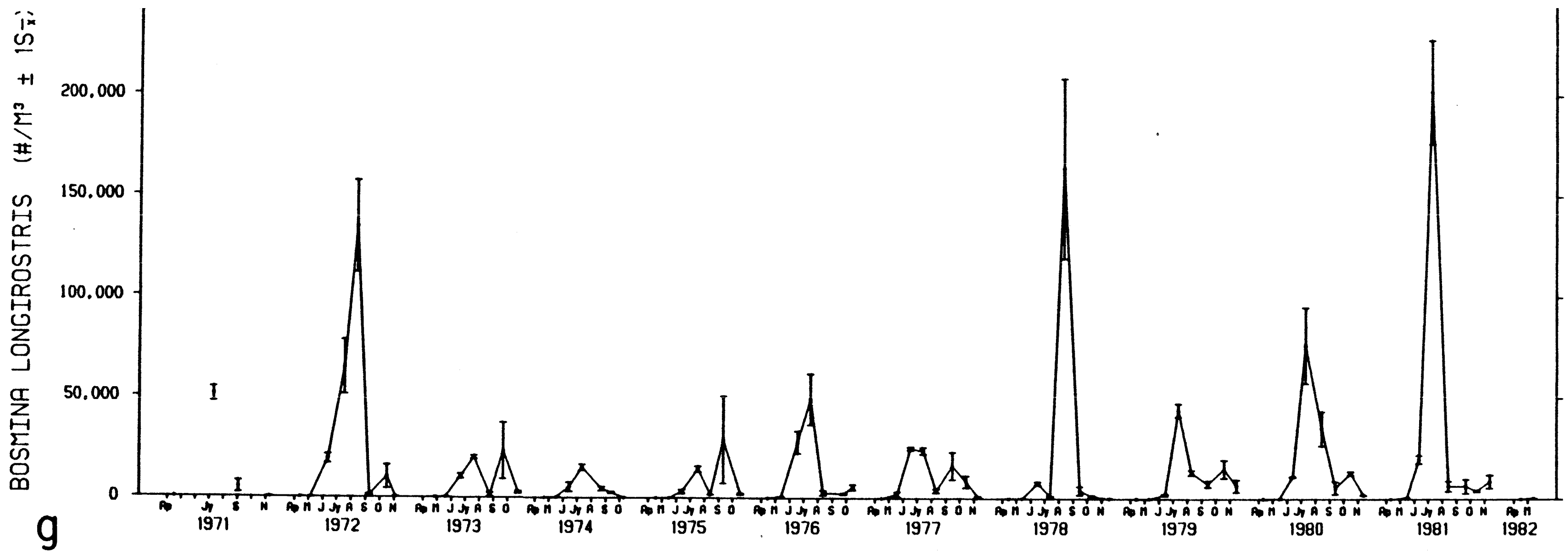


Fig. 31. Continued. e) <u>Diaptomus</u> spp. C6, f) <u>Eurytmora affinis</u> C1-C6,



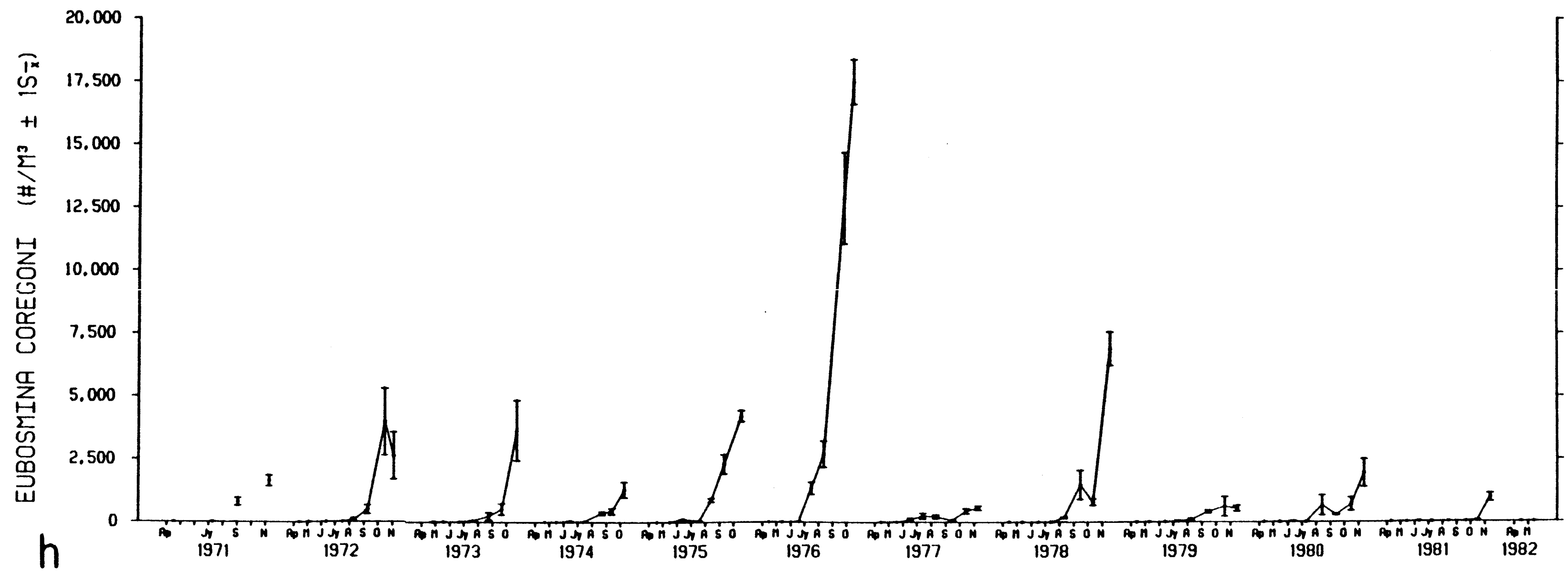


Fig. 31. Continued. g) Bosmina longirostris, h) Eubosmina coregoni,

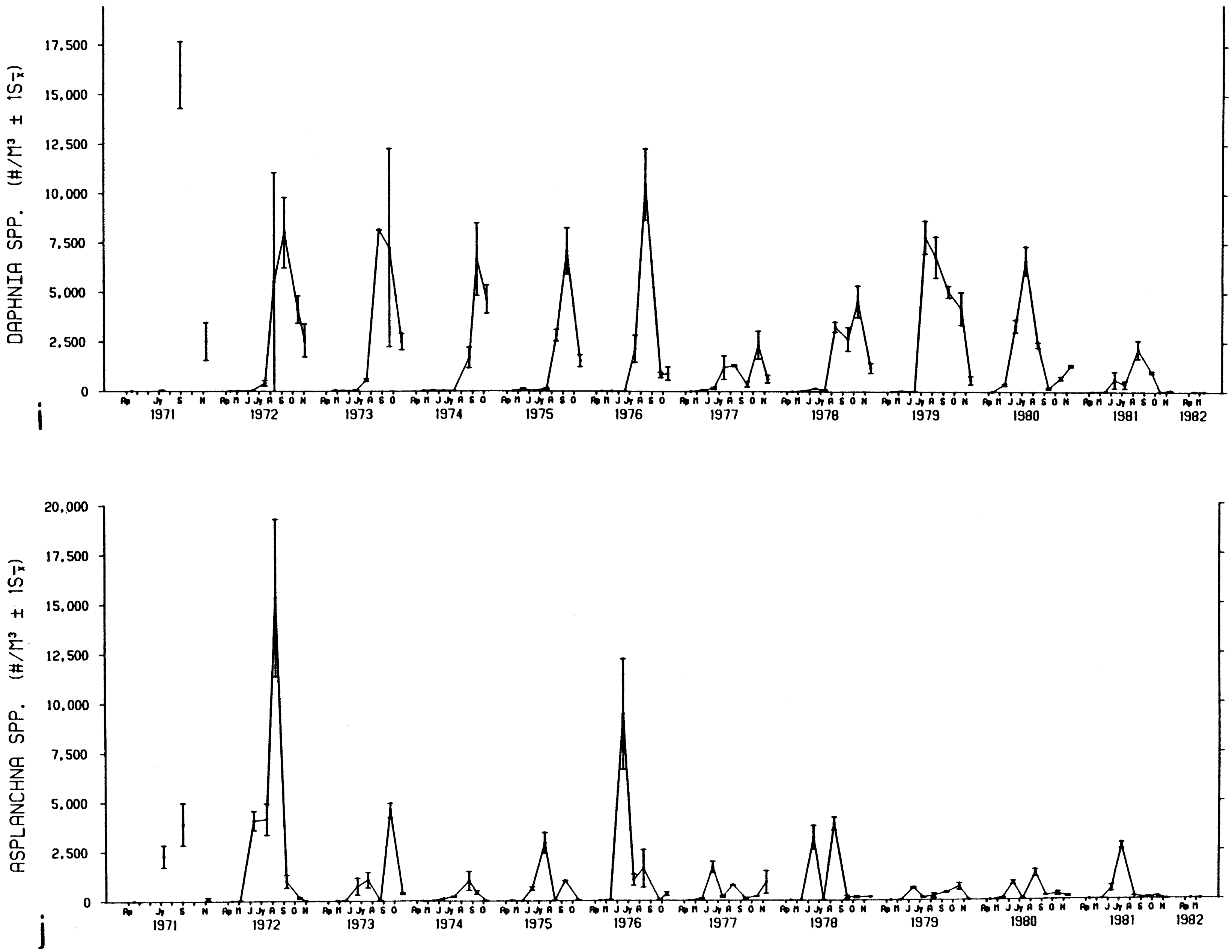


Fig. 31. Concluded. i) Daphnia spp., j) Asplanchna spp.

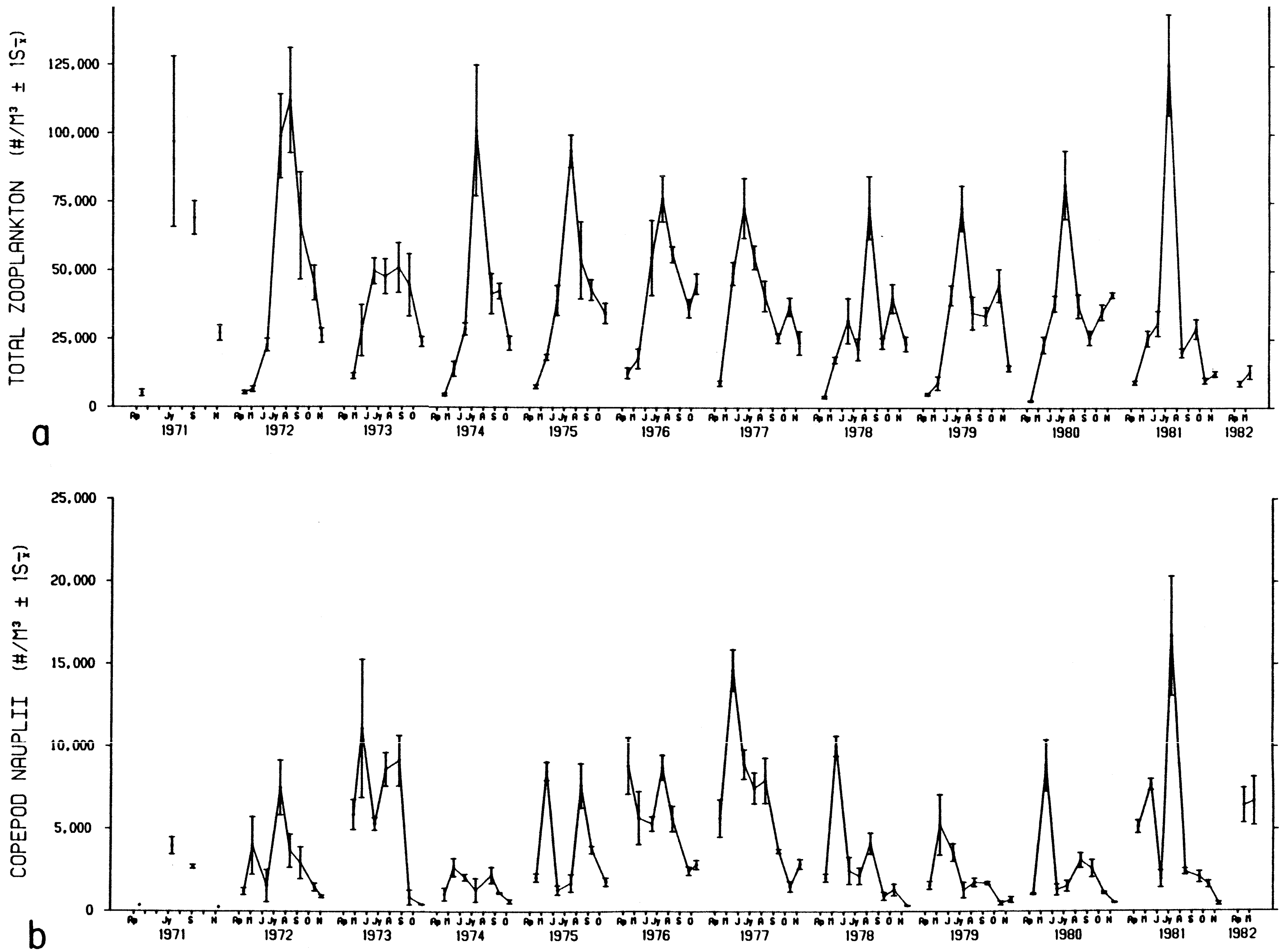


Fig. 32. The monthly abundance of zooplankton in the inner offshore zone (zone 7) between 1970 and 1982. a) Total zooplankton, b) copepod nauplii,

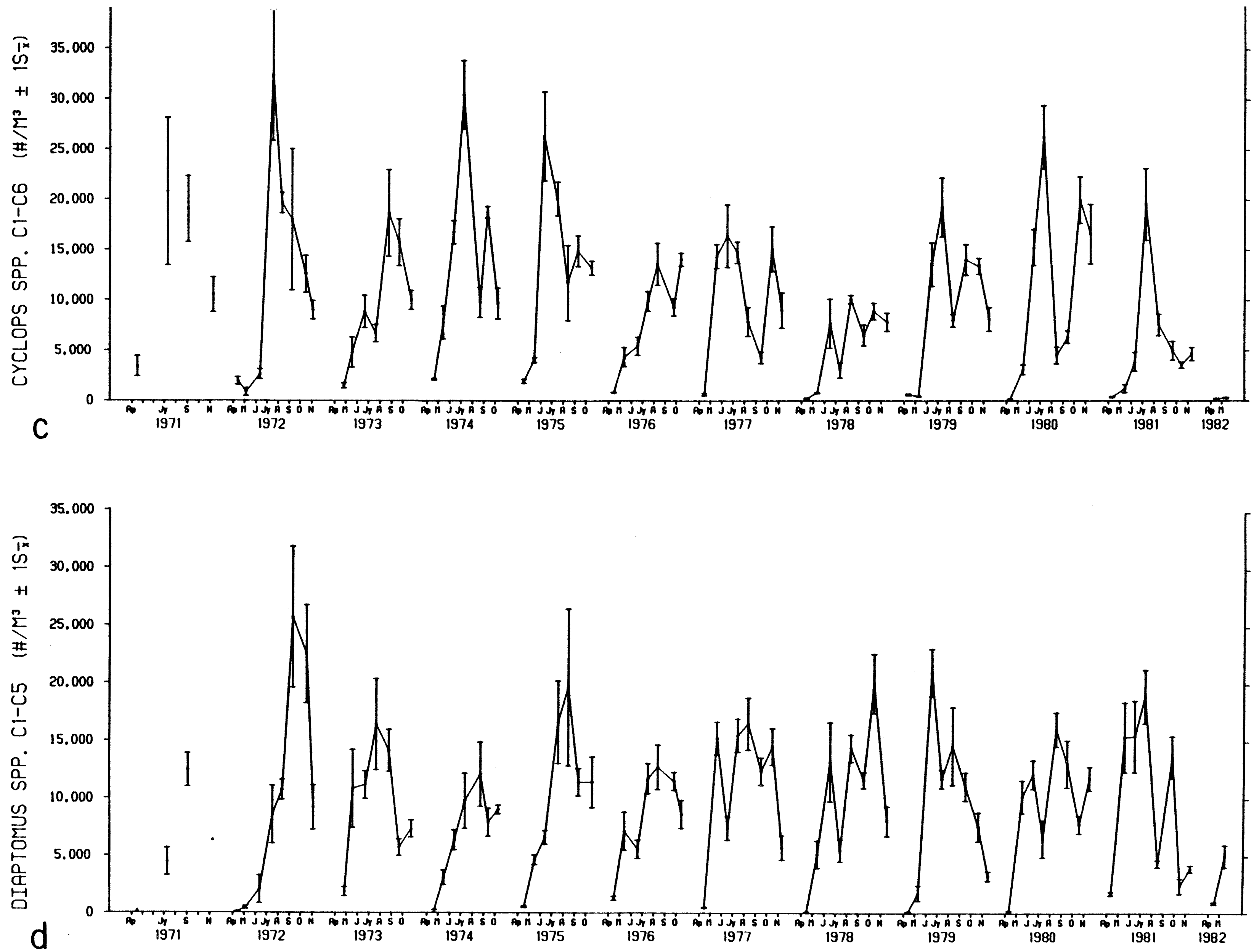


Fig. 32. Continued. c) cyclopoid copepods C1-C6, d) Diaptomus spp. C1-C5,

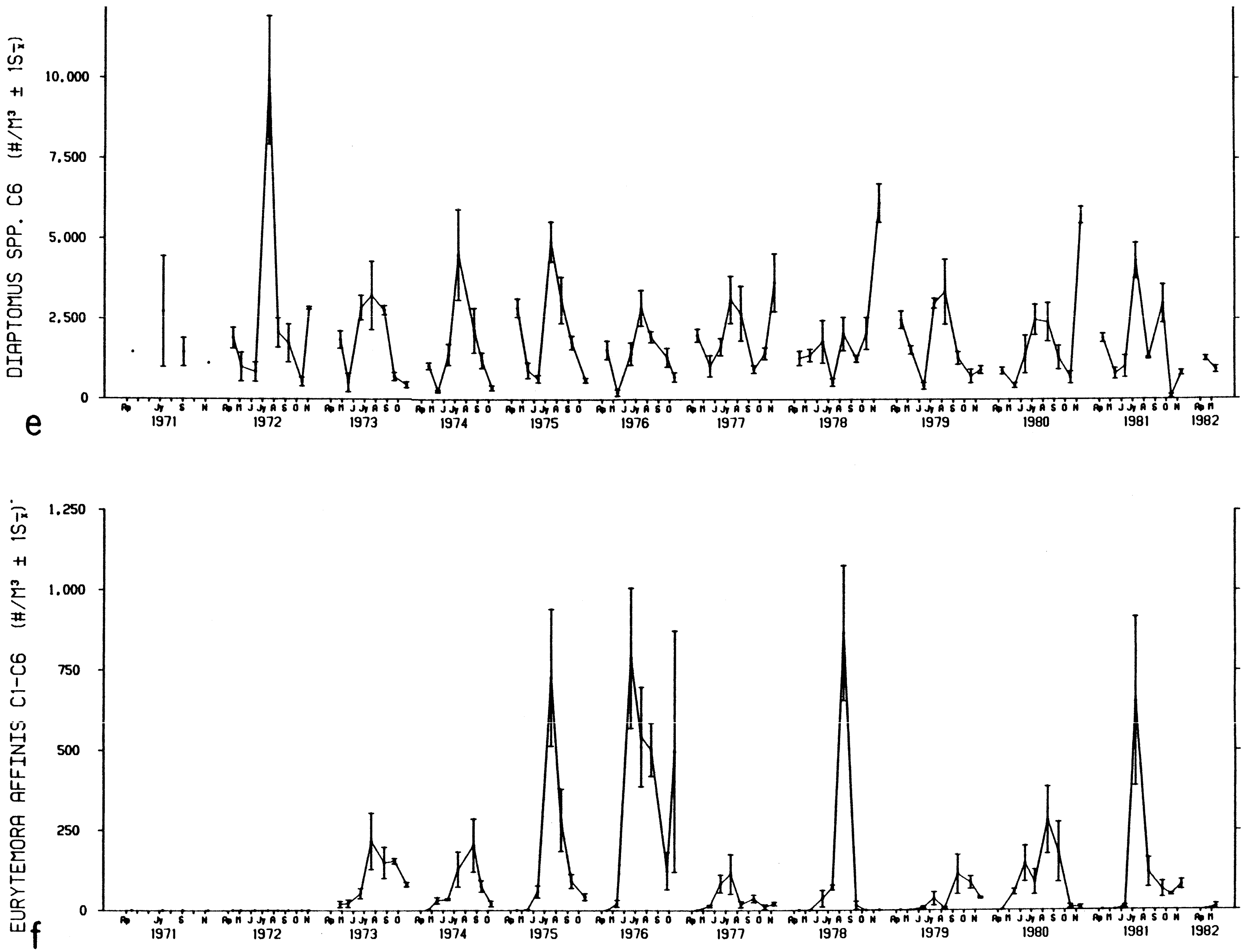


Fig. 32. Continued. e) <u>Diaptomus</u> spp. C6, f) <u>Eurytmora affinis</u> C1-C6,

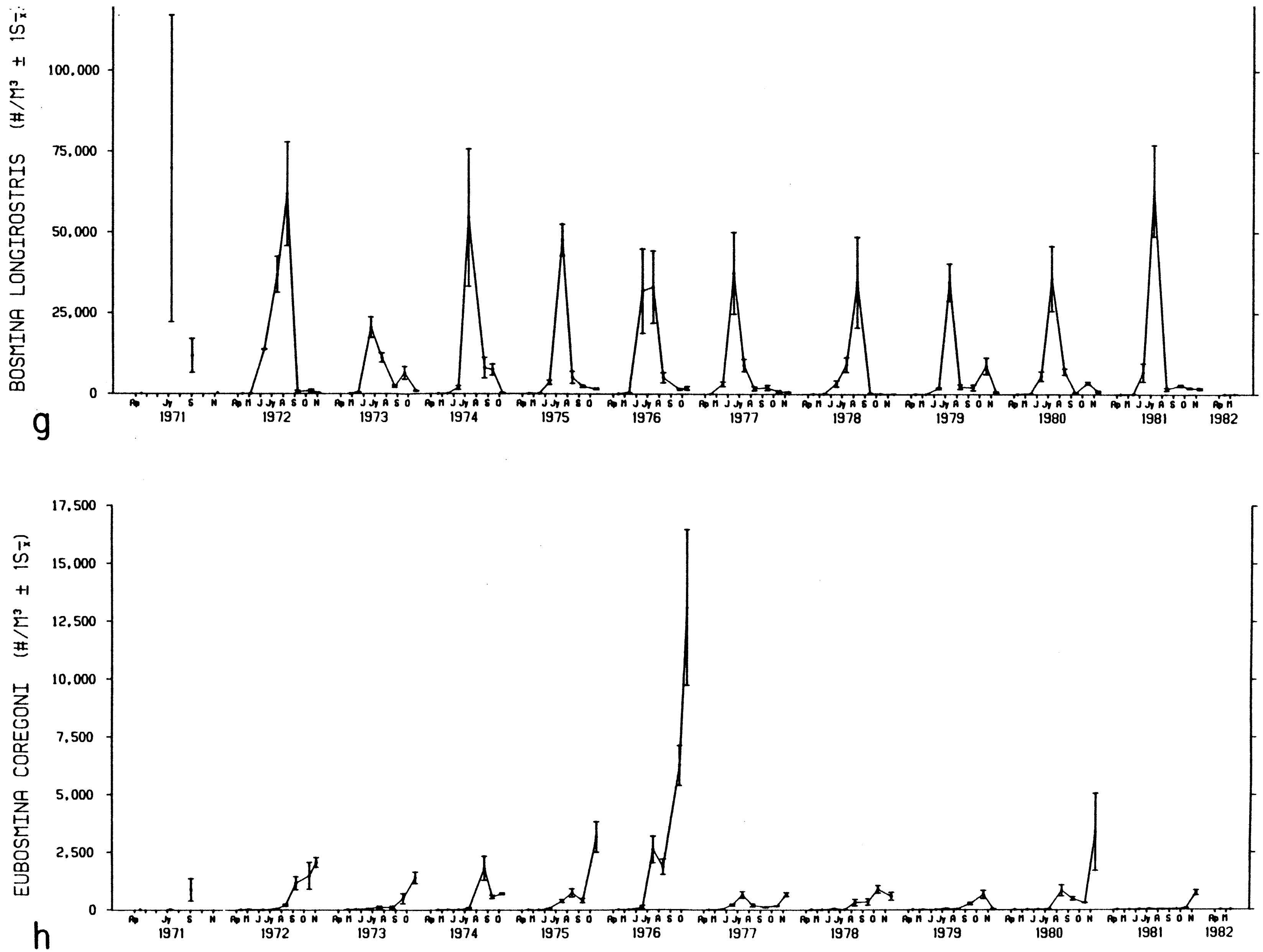


Fig. 32. Continued. g) Bosmina longirostris, h) Eubosmina coregoni,

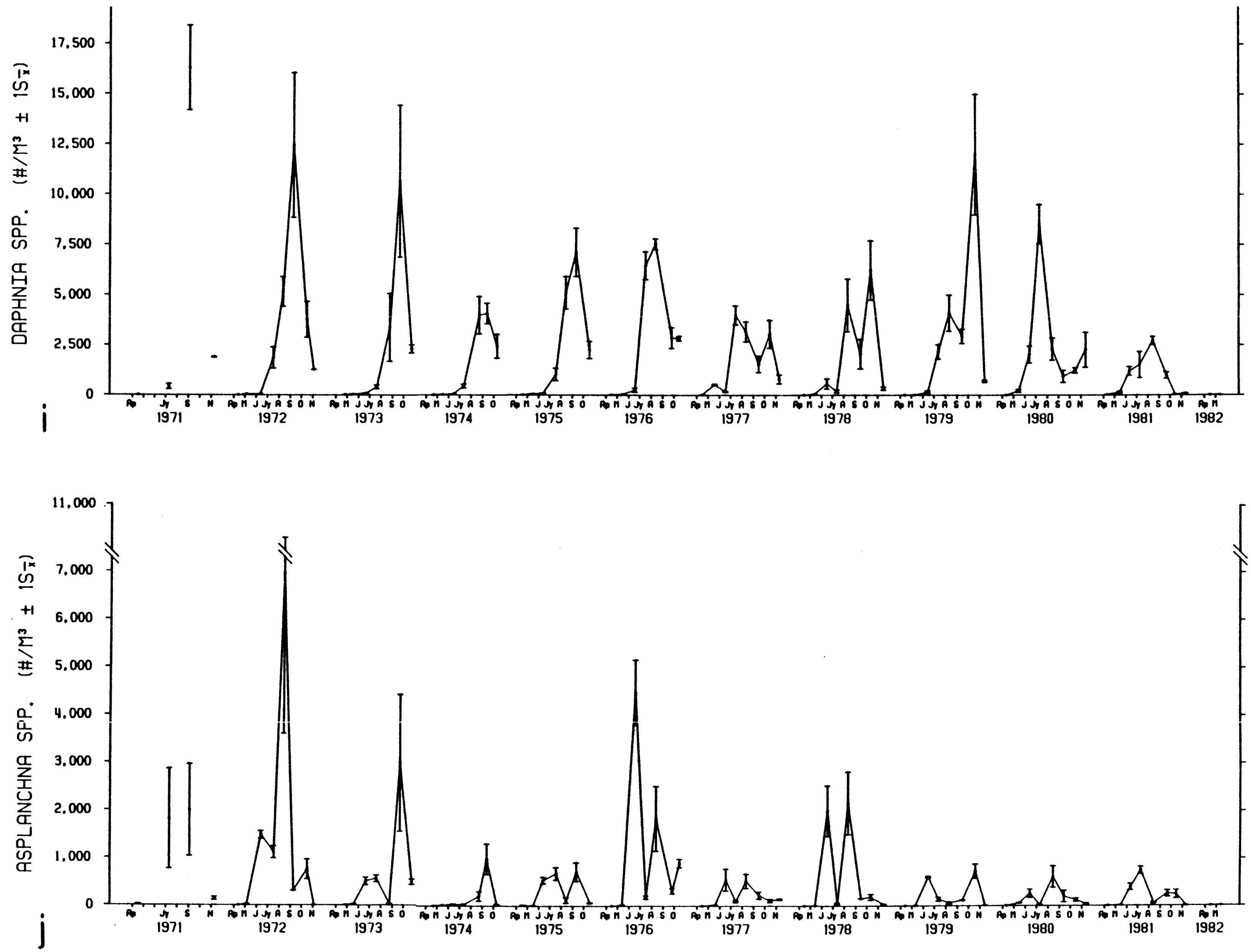


Fig. 32. Concluded. i) Daphnia spp., j) Asplanchna spp.

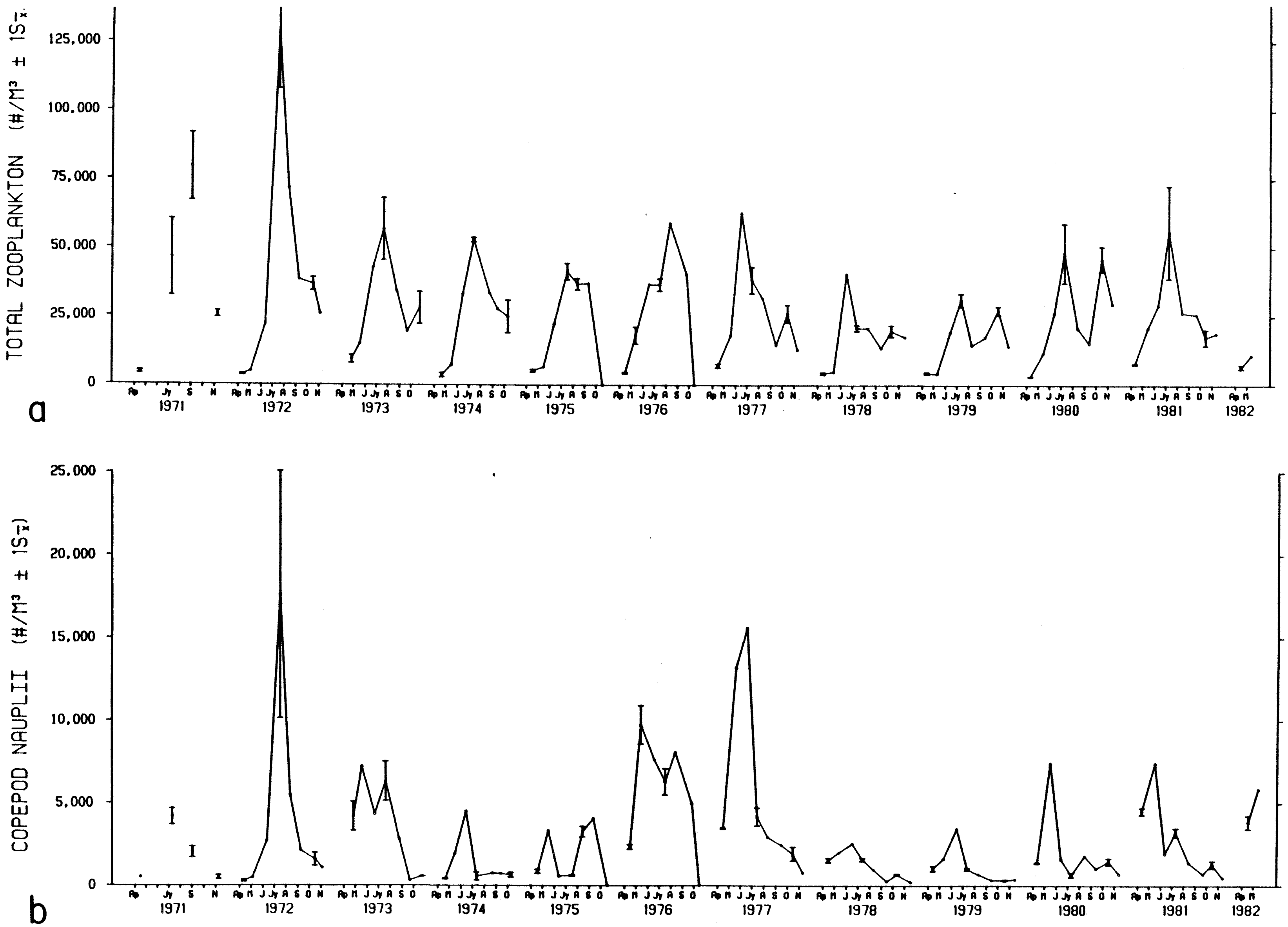


Fig. 33. The monthly abundance of zooplankton in the outer offshore zone (zone 8) between 1970 and 1982. a) Total zooplankton, b) copepod nauplii,

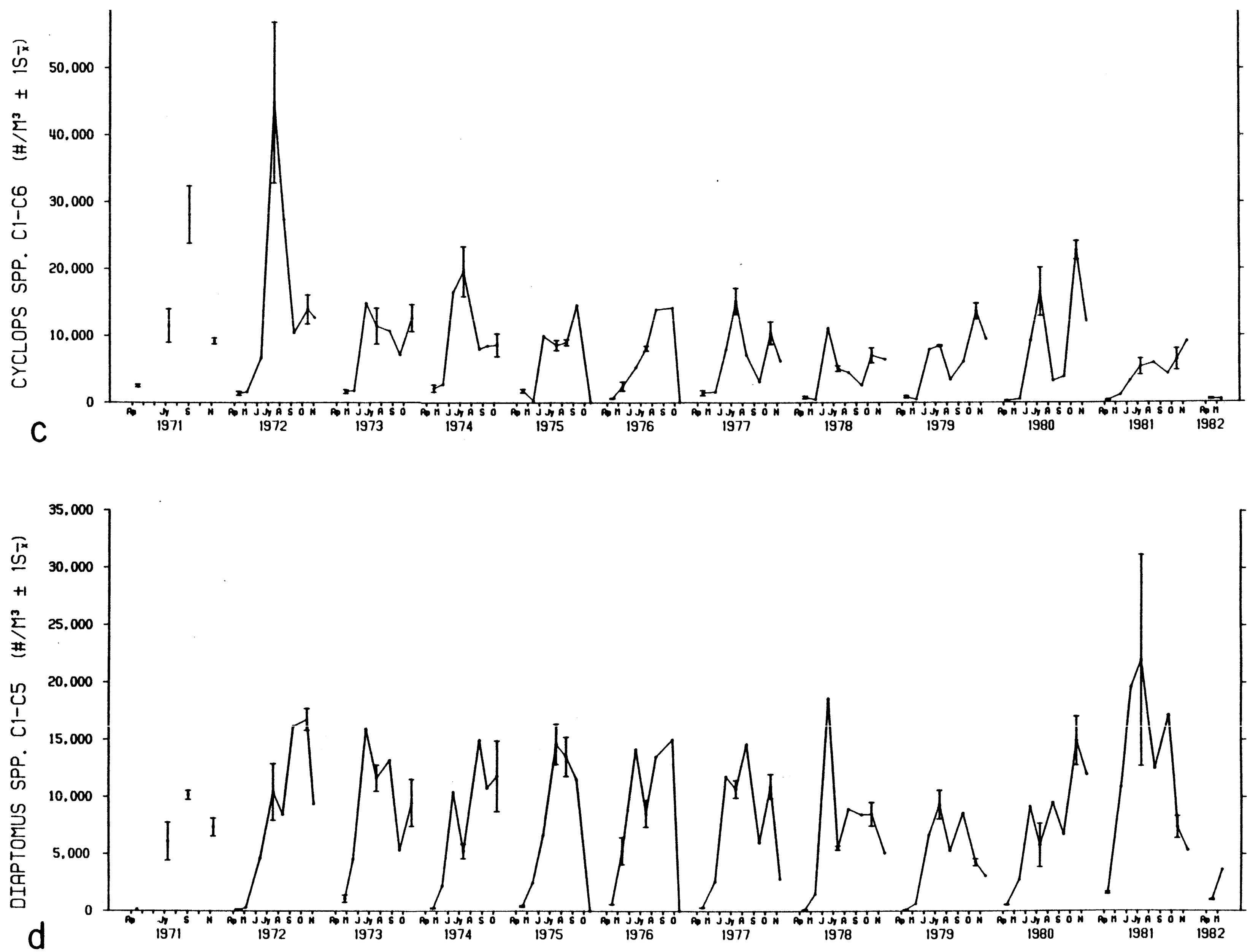


Fig. 33. Continued. c) cyclopoid copepods C1-C6, d) *Diaptomus* spp. C1-C5,

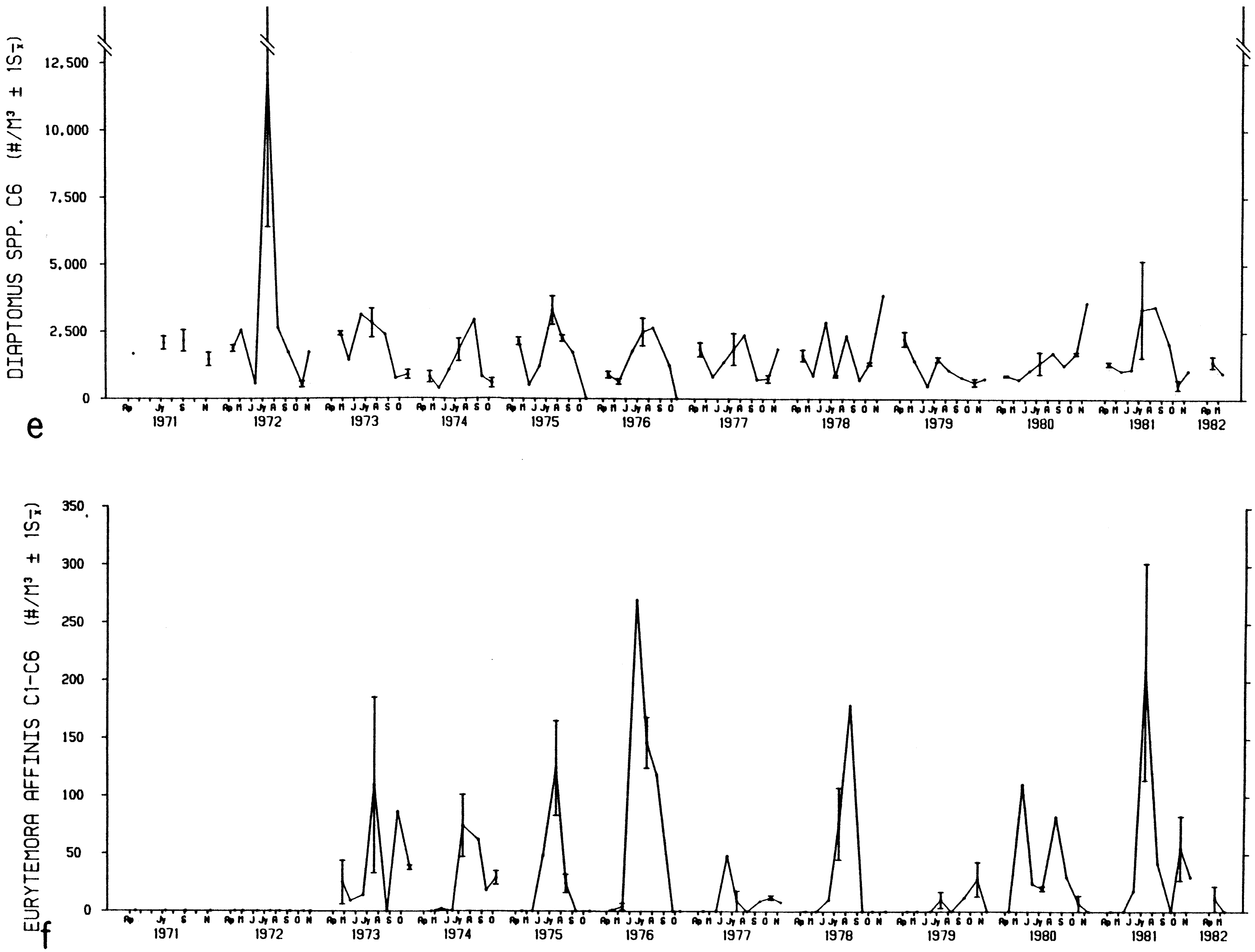


Fig. 33. Continued. e) Diaptomus spp. C6, f) Eurytmora affinis C1-C6,

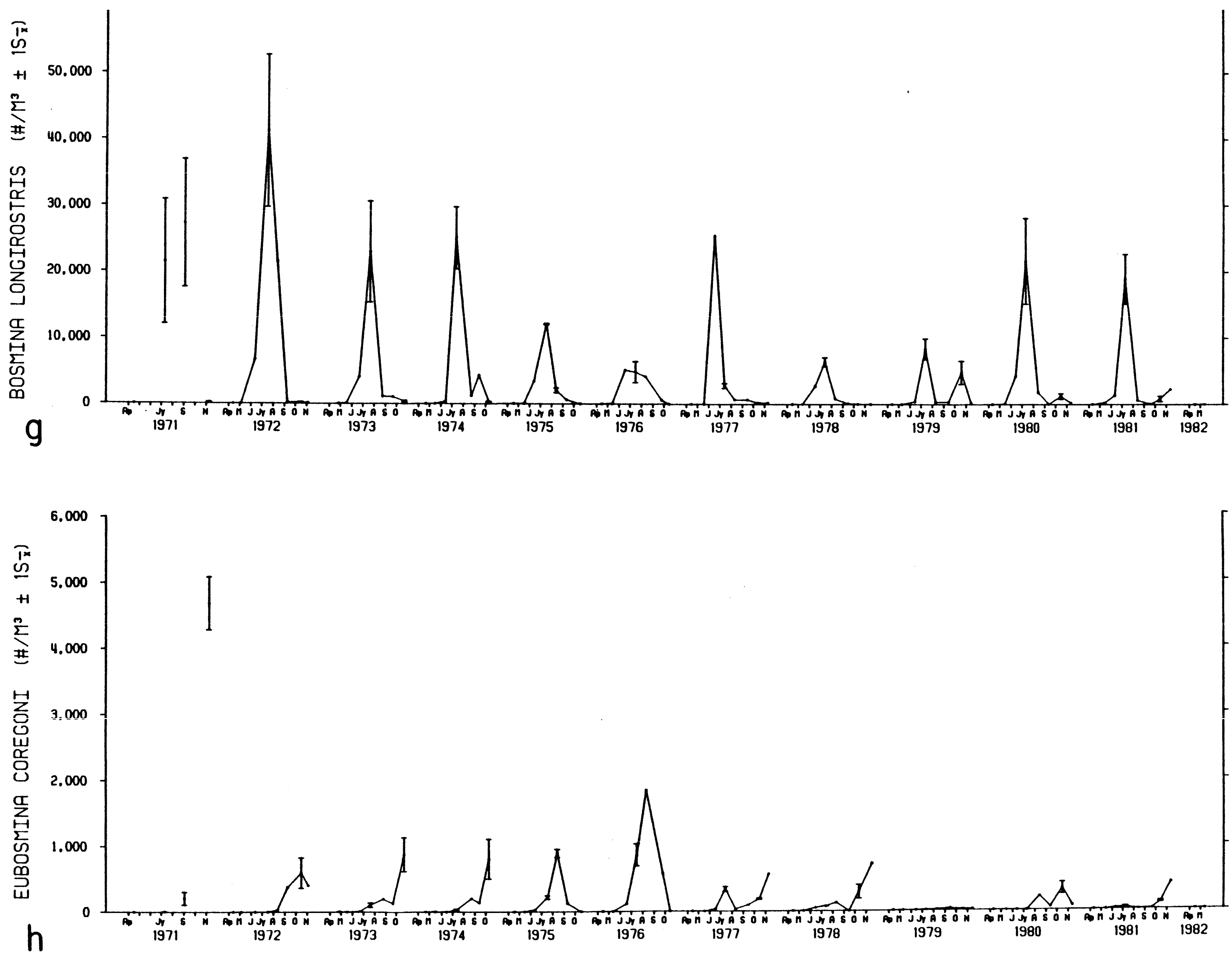


Fig. 33. Continued. g) Bosmina longirostris, h) Eubosmina coregoni,

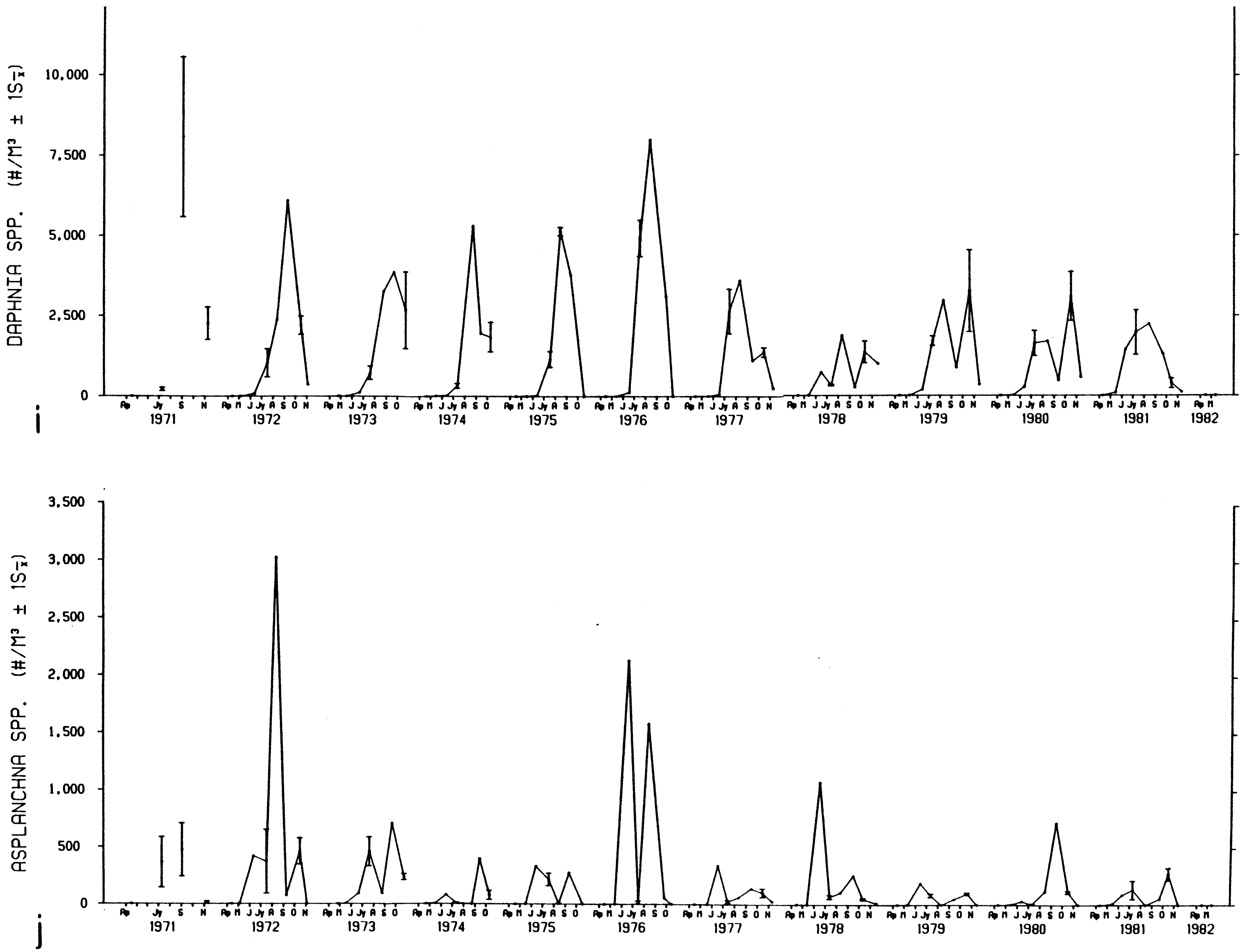


Fig. 33. Concluded. i) Daphnia spp., j) Asplanchna spp.

8 (outer offshore zone) were examined to determine the major features of their seasonal cycles and long-term trends. In zones 2 and 5, these patterns were compared in the preoperational and operational periods to investigate whether or not power plant operation had any apparent effect on zooplankton temporal succession and population trends in the vicinity of the plume (Figs. 30 and 31). Similar plots for zones 7 and 8 provide information on temporal succession in the offshore region of southeastern Lake Michigan (Figs. 32 and 33).

Overall, in zones 2 and 5, temporal succession patterns were similar in the operational and preoperational periods (Figs. 30 and 31). For the most part, the range of population densities observed in the preoperational period were not exceeded in the operational period. Exceptions were adult *Diaptomus* spp., *Eurytemora affinis* C1-C6, and *Eubosmina coregoni* whose maximum attained abundances in the operational period were 1.5 to 5 times those attained in the preoperational period. *Eurytemora affinis* and *Eubosmina coregoni* also attained greater abundances in zone 7 (Fig. 32) in the operational period than in the preoperational period. This suggests that peak abundances of *E. affinis* and *E. coregoni* in the operational period were related to a widespread event occurring in the southeastern basin of Lake Michigan. High operational abundances of *Diaptomus* spp. (Fig. 30) in zone 2 occurred in April and August 1975, April 1977, November 1978, and November 1980 and, in zone 5, in April 1975, November 1978, August and November 1980, and September 1981. High April abundances are discussed below in the statistical analysis of preoperational and operational cruises.

Temporal succession patterns were similar in the preoperational and operational periods. Zooplankton occurred in low numbers in spring and

increased in abundance through summer. Often a mid-summer decline in numbers was followed by an autumn pulse. Copepod nauplii, immature calanoid and cyclopoid copepodites, and adult Diaptomus species occurred in relatively low numbers in spring with maximum population size attained in summer or autumn. Temporal succession patterns of Bosmina longirostris, a summer-autumn cladoceran, were similar during the preoperational and operational periods. This species did not appear earlier in the plankton nor persist for longer periods of time after the plant became operational. In the preoperational period, Daphnia spp. occurred in maximum numbers primarily in the late summer and autumn: this continued to be observed in the operational period. In zone 2, Eubosmina coregoni did not increase markedly in abundance until late September-early October in the preoperational period. After the plant became operational, it tended to occur in somewhat greater numbers in zone 2 in mid-summer than observed in the preoperational period. However, this also was observed in zone 7, suggesting that the earlier summer increase in Eubosmina coregoni was not directly related to plant operation.

General Features of Statistical Comparisons between Preoperational and Operational Abundances

Statistical comparisons of zooplankton abundances in the preoperational and operational time periods were based on non-parametric statistical analyses of the eight zones comprising the survey grid. Analyses show that zooplankton abundances in the vicinity of the power plant were statistically different between the two time periods. Since zooplankton abundances in control zones located north and south of the inshore and offshore plume zones (Fig. 29) show similar trends, we conclude that such preoperational-operational differences probably are not directly due to power plant operation. Ecological factors

affecting these long-term changes are discussed in Evans and Jude (1986), Evans (1986), and Scavia et al. (1986).

Statistical Comparisons of April Preoperational (1971-1974) with Operational (1975-1982) Abundances

In this section, we report the results of the Mann-Whitney U tests of taxa abundances by major survey cruise and for each of the eight zones.

Nine taxa were examined for preoperational-operational differences in abundance in each of the eight depth zones. All taxa (Table 7, Fig. 34), with the exception of immature Diaptomus spp. copepodites, exhibited statistically significant (α=0.05) differences between preoperational and operational abundances in at least one of the eight depth zones.

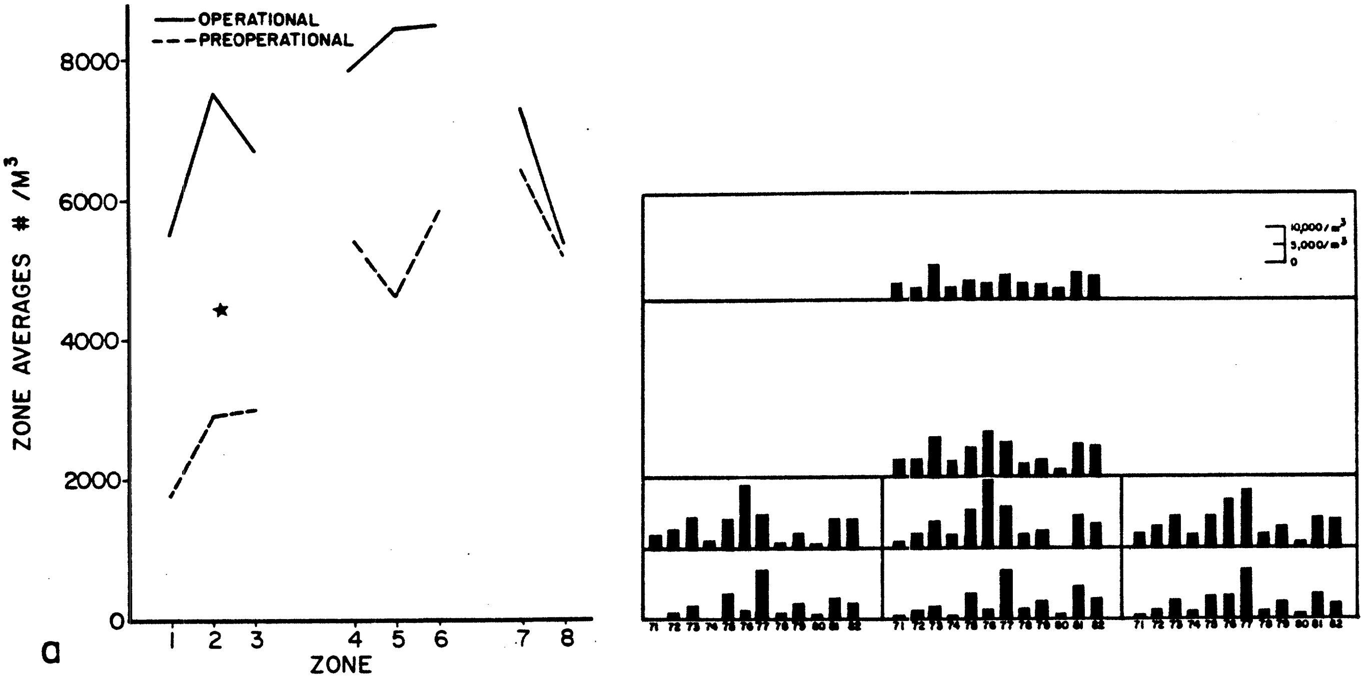
Total mean zooplankton densities generally were statistically similar for the preoperational and operational periods (Fig. 34a), although zooplankton operational means were higher than preoperational zone means. In zone 2 (inshore plume zone) zooplankton were significantly more abundant in the operational period; abundances in the operational period were more than twice the preoperational mean. Copepod nauplii tended to be more abundant in the operational period than in the preoperational period (Fig. 34b). Differences were statistically significant only for zone 2; abundances were approximately twice as great in the operational period as in the preoperational period.

Immature cyclopoid copepodites (Fig. 34c) were significantly less abundant (by a factor of two to three) in the operational period than in the preoperational period in all but zone 1. Zone 1 preoperational and operational densities were nearly identical. Preoperational mean abundances of adult Cyclops spp. in the inshore zones (1, 2, and 3) were lower than

Table 7. Results of the Mann-Whitney U tests comparing April preoperational and operational densities of nine zooplankton taxa in each of eight zones. The preoperational period is 1971-74 or a subset ending in 1974, and the operational period is 1975-82.

Taxon	Zone 1	2	3	4	5	6	7	8	Period
Order and Suborder Level									
Copepod nauplii	NS	*	NS	NS	NS	NS	NS	NS	72-82
Cyclopoids (C1-C6)	NS	NS	NS	*	*	*	*	*	71-82
Calanoids (C1-C6)	*	*	*	NS	*	*	NS	NS	71-82
Genus and Developmental Stage									
Cyclopoids (C1-C5)	NS	*	*	*	*	*	*	*	73-82
Cyclops spp. C6	NS	NS	NS	NS	NS	NS	*	*	73-82
Diaptomus spp. (C1-C5)	NS	NS	NS	NS	NS	NS	NS	NS	73-82
Diaptomus spp. C6	NS	*	NS	NS	*	*	NS	NS	73-82
Limnocalanus macrurus (C1-C6)	*	*	*	*	*	*	NS	NS	71-82
Total zooplankton	NS	*	NS	NS	NS	NS	NS	NS	72-82

*significant difference, $\alpha = 0.05$.
NS not significant.



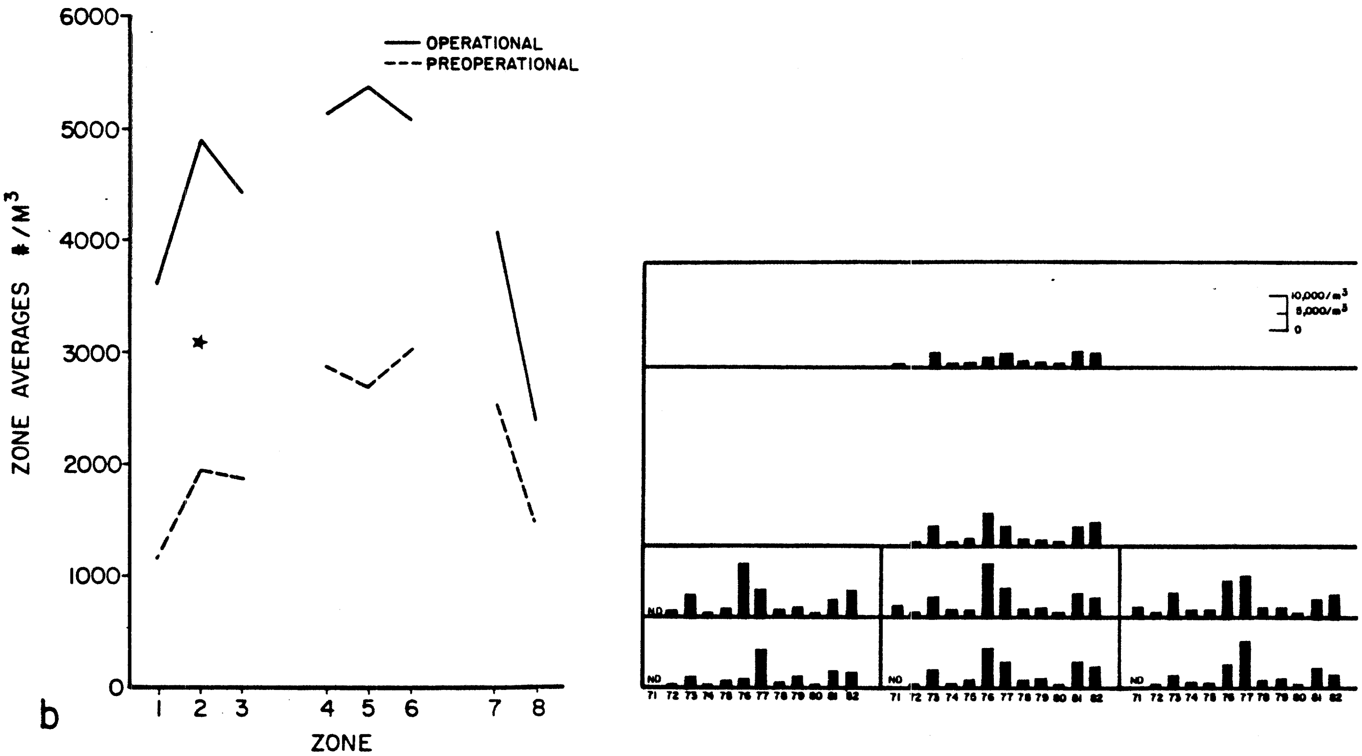
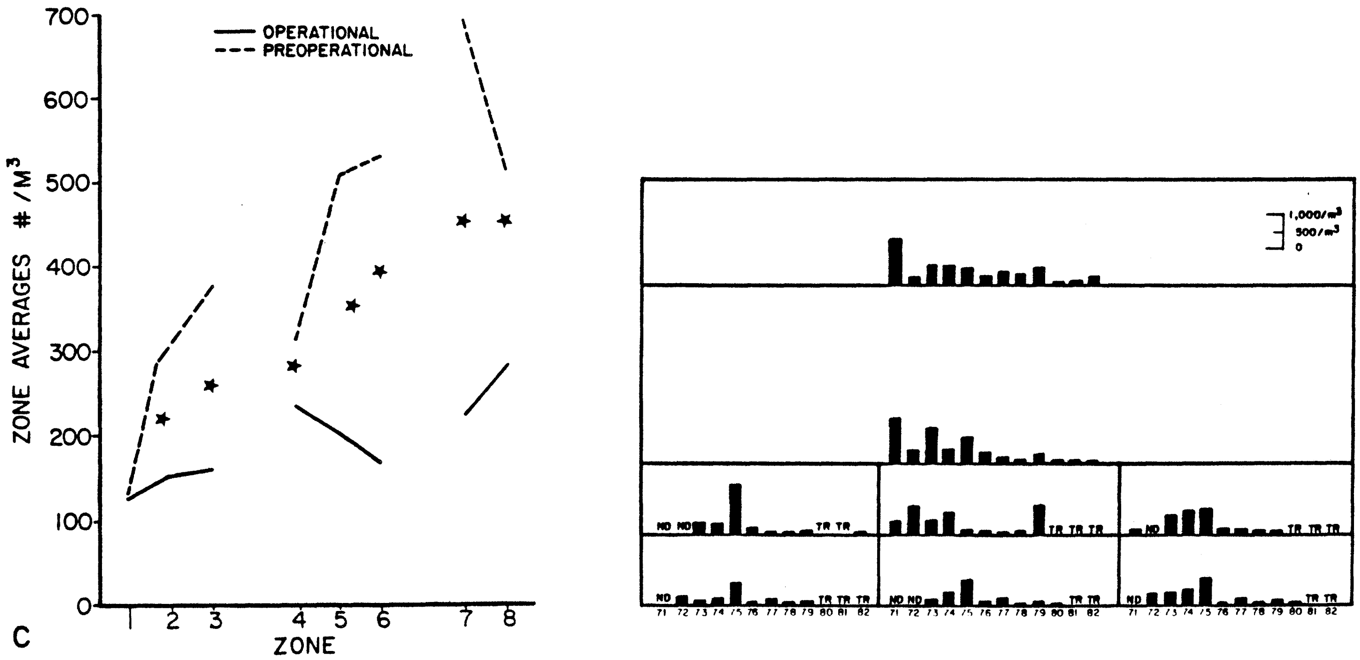


Fig. 34. The mean April preoperational (1971-1974) and operational (1975-1982) densities of zooplankton taxa by depth, zone, and year. The right side panel for each figure shows the mean densities for each year and depth zone in histograms. The left panel shows the mean preoperational (1971-1974) and operational (1975-1982) period (dashed and solid lines respectively) densities for each zone. Lines connect zones in the same depth grouping: inshore, middle, and inner and outer offshore zones. Stars indicate zones with significantly different preoperational and operational densities (Mann-Whitney U test α = 0.5). ND = no data, TR = trace, Z = zero. a) Total zooplankton, b) copepod nauplii,



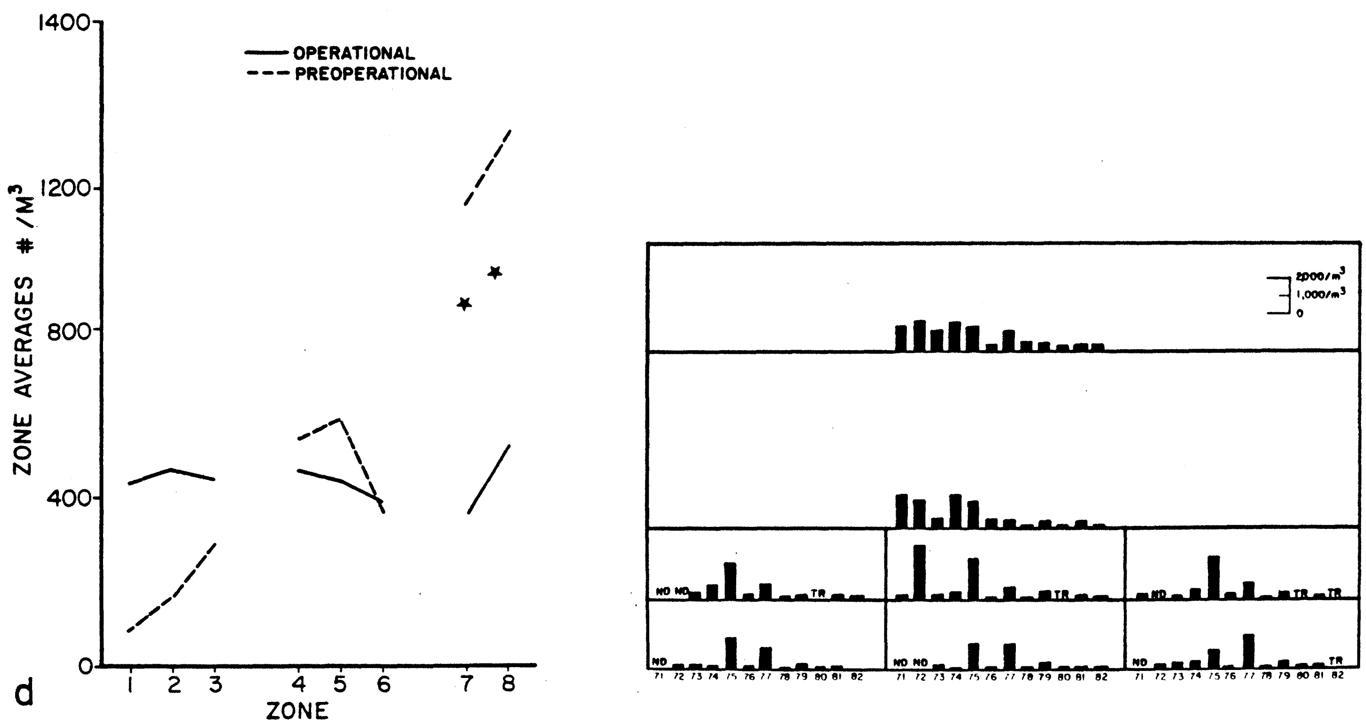
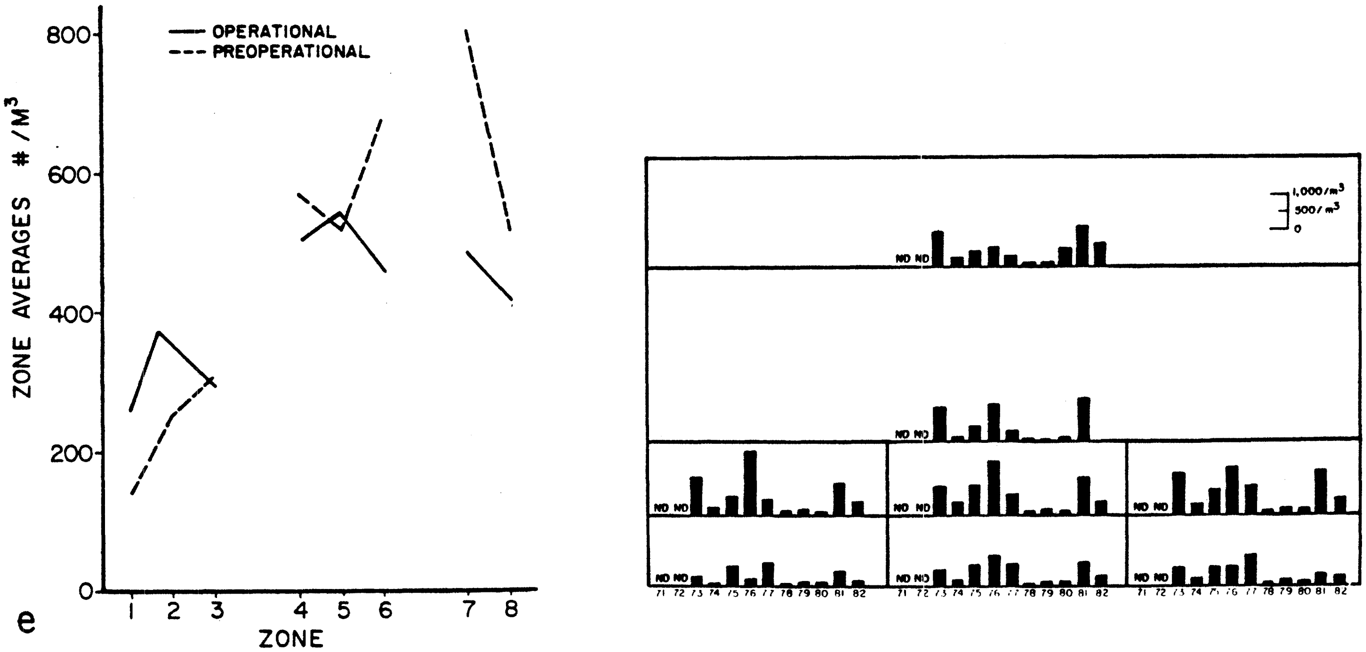


Fig. 34. Continued. c) cyclopoid copepods C1-C5, d) *Cyclops* spp. C6,



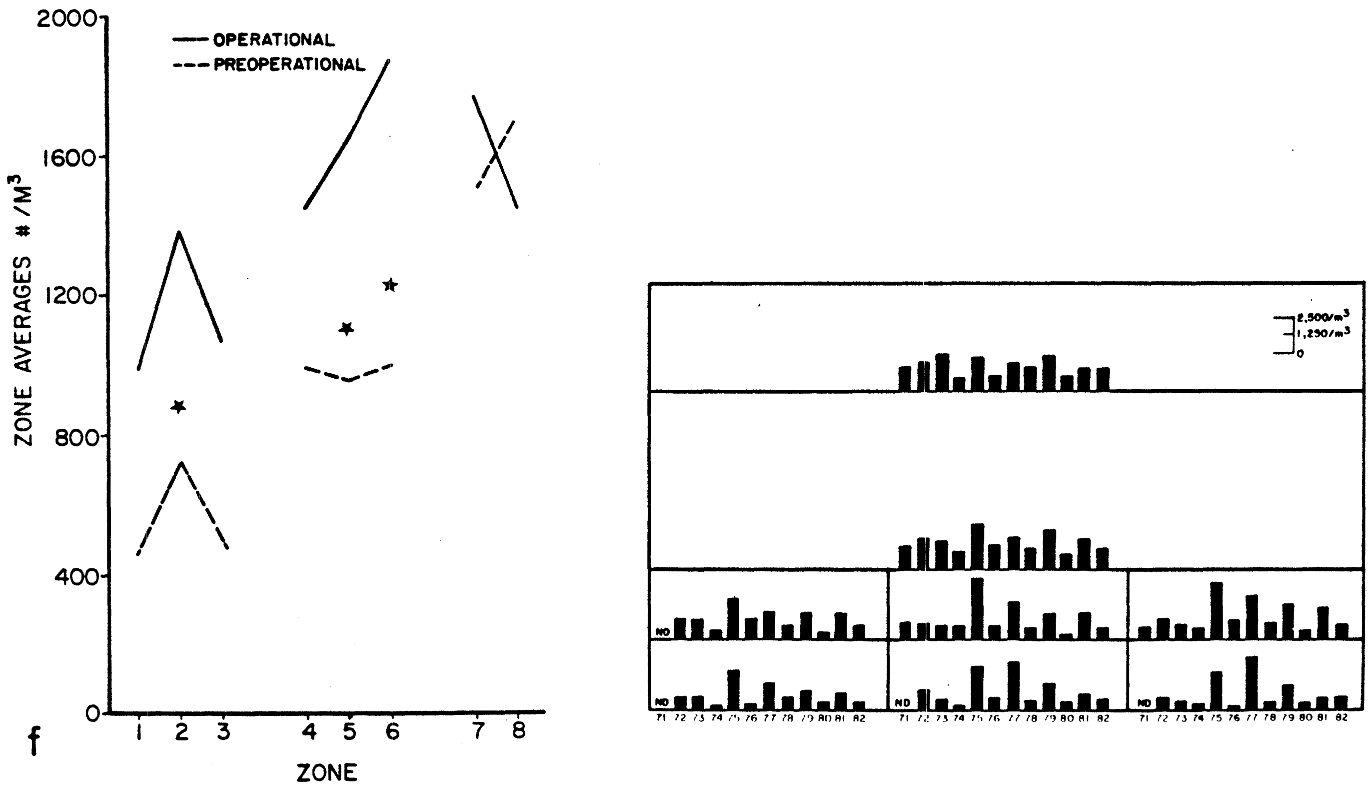
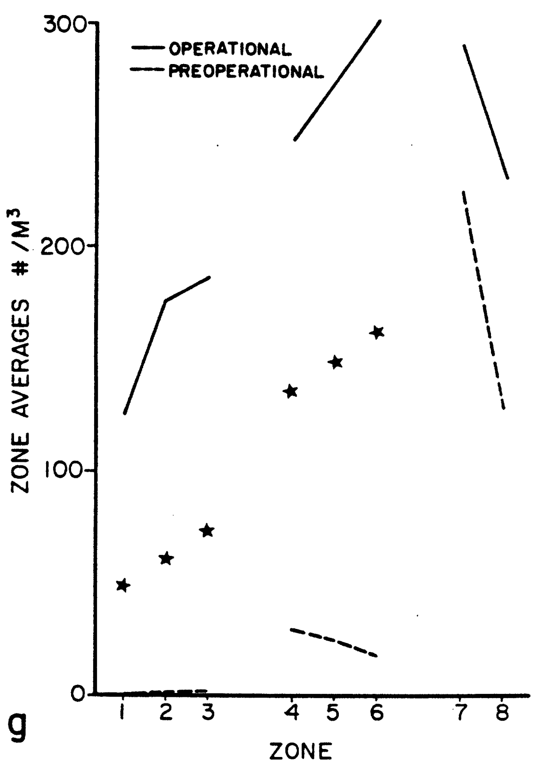


Fig. 34. Continued. e) Diaptomus spp. C1-C5, f) Diaptomus spp. C6,



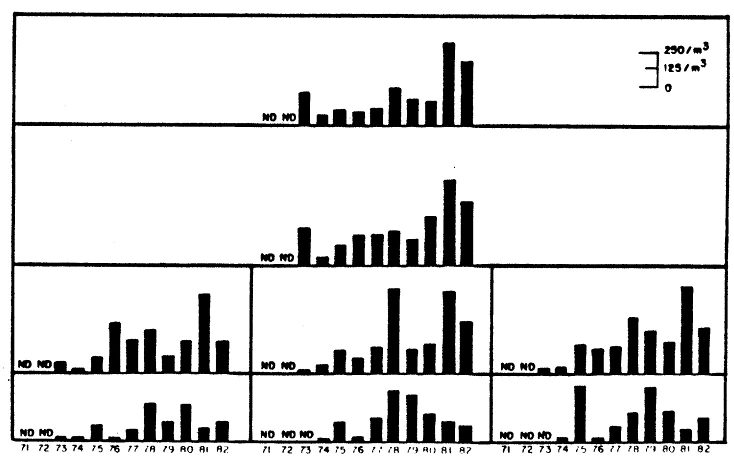


Fig. 34. Concluded. g) _Limnocalanus macrurus_ C1-C6.

operational means, but not significantly so. In the middle and offshore zones, preoperational means were generally higher than operational means; these differences were statistically significant only in zones 7 and 8, where adult Cyclops spp. abundances differed significantly between the preoperational and operational periods. Adult Cyclops spp. operational abundances were one-half to one-third preoperational abundances.

Immature Diaptomus spp. copepodites displayed no consistent trends in mean abundance between preoperational and operational periods in the inshore and middle depth zones. The higher preoperational abundances in zones 7 and 8 (inner and outer offshore zones) were not statistically significant. With the exception of zone 8, adult Diaptomus spp. mean operational abundances were higher than preoperational abundances. Adult Diaptomus spp. abundances (Fig. 34f) were significantly greater (a factor of less than two) in the operational period than in the preoperational period in zones 2, 5, and 6. Limnocalanus macrurus abundances increased markedly in the operational period with differences statistically significant in zones 1, 2, 3, 4, 5, and 6, i.e., the inshore and middle zones (Fig. 34g). Abundance increases ranged from a factor of 11 (zone 5) to more than 200 (zone 1). Lower preoperational abundances in the offshore regions (zones 7 and 8) were not statistically significant.

Statistical Comparisons of July Preoperational with Operational (1975-1981) Abundances

Thirteen taxa were examined for preoperational-operational period differences in each of the eight zones of the survey grid in July. All taxa, with the exception of Eurytemora affinis, exhibited statistically significant

(α=0.05) differences between preoperational and operational periods in at least one of the eight zones (Table 8).

Total mean zooplankton densities generally were statistically similar for the preoperational and operational periods (Fig. 35a). The one exception was the outer offshore zone (zone 8), where operational densities were approximately half those observed in the preoperational period.

Among the crustaceans, copepod nauplii densities (Fig. 35b) were significantly (α=0.05) higher in the operational period than in the preoperational period only in zone 1, the southern inshore control zone. Operational densities were three times preoperational densities. Elsewhere, copepod nauplii tended to be less abundant in the operational period than in the preoperational period, although differences were not statistically significant.

Immature cyclopoid copepodites showed no consistent trends in change throughout the survey area (Fig. 35c). Preoperational to operational decreases in abundance occurred in approximately half of the zones of the survey grid. Only one contrast was statistically (α=0.05) significant; this occurred in the inshore plume zone 2. Statistically significant operational decreases (by a factor of about two) in abundance of *Cyclops* spp. adults (primarily *C. bicuspidatus thomasi*) were observed in the inshore plume zone (zone 2) and the outer offshore zone (zone 8) (Fig. 35d). All other zone abundances generally were similar between the two time periods.

Immature *Diaptomus* spp. copepodites (Fig. 35e) were less abundant in the operational period than in the preoperational period in seven of the eight survey area zones. The outer offshore zone was the only exception. These declines were statistically significant (α=0.05) only in the plume and

Table 8. Results of the Mann-Whitney U tests comparing July preoperational and operational densities of thirteen zooplankton taxa in each of eight zones. The preoperational period is 1971-74 or a subset ending in 1974, and the operational period is 1975-81. In column 1, results shown are from student's t-test analysis ($p < 0.05$) of the 3 inshore zones combined.

Taxon	Zone 1-3	1	2	3	4	5	6	7	8	Period
Order and Suborder Level										
Cladocerans	NS	NS	NS	NS	NS	NS	NS	NS	*	71-81
Copepod nauplii	NS	*	NS	NS	NS	NS	NS	NS	NS	72-81
Cyclopoids (C1-C6)	NS	NS	*	NS	NS	NS	NS	NS	*	71-81
Calanoids (C1-C6)	*	NS	*	NS	NS	NS	NS	NS	NS	71-81
Genus, Species or Developmental Stage										
Bosmina longirostris	NS	NS	NS	NS	NS	NS	NS	NS	*	72-81
Daphnia spp.	*	*	*	*	*	*	*	*	*	71-81
Cyclopoids (C1-C5)	NS	NS	*	NS	NS	NS	NS	NS	NS	73-81
Cyclops spp. C6	*	NS	*	NS	NS	NS	NS	NS	*	73-81
Diaptomus spp. (C1-C5)	*	NS	*	*	NS	NS	NS	NS	NS	73-81
Diaptomus spp. C6	*	NS	*	*	*	*	NS	NS	NS	73-81
Eurytemora affinis (C1-C6)	NS	NS	NS	NS	NS	NS	NS	NS	NS	73-81
Asplanchna spp.	*	NS	*	*	NS	*	*	*	NS	71-81
Total zooplankton	NS	NS	NS	NS	NS	NS	NS	NS	*	72-81

*significant difference, $\alpha = 0.05$.
NS not significant.

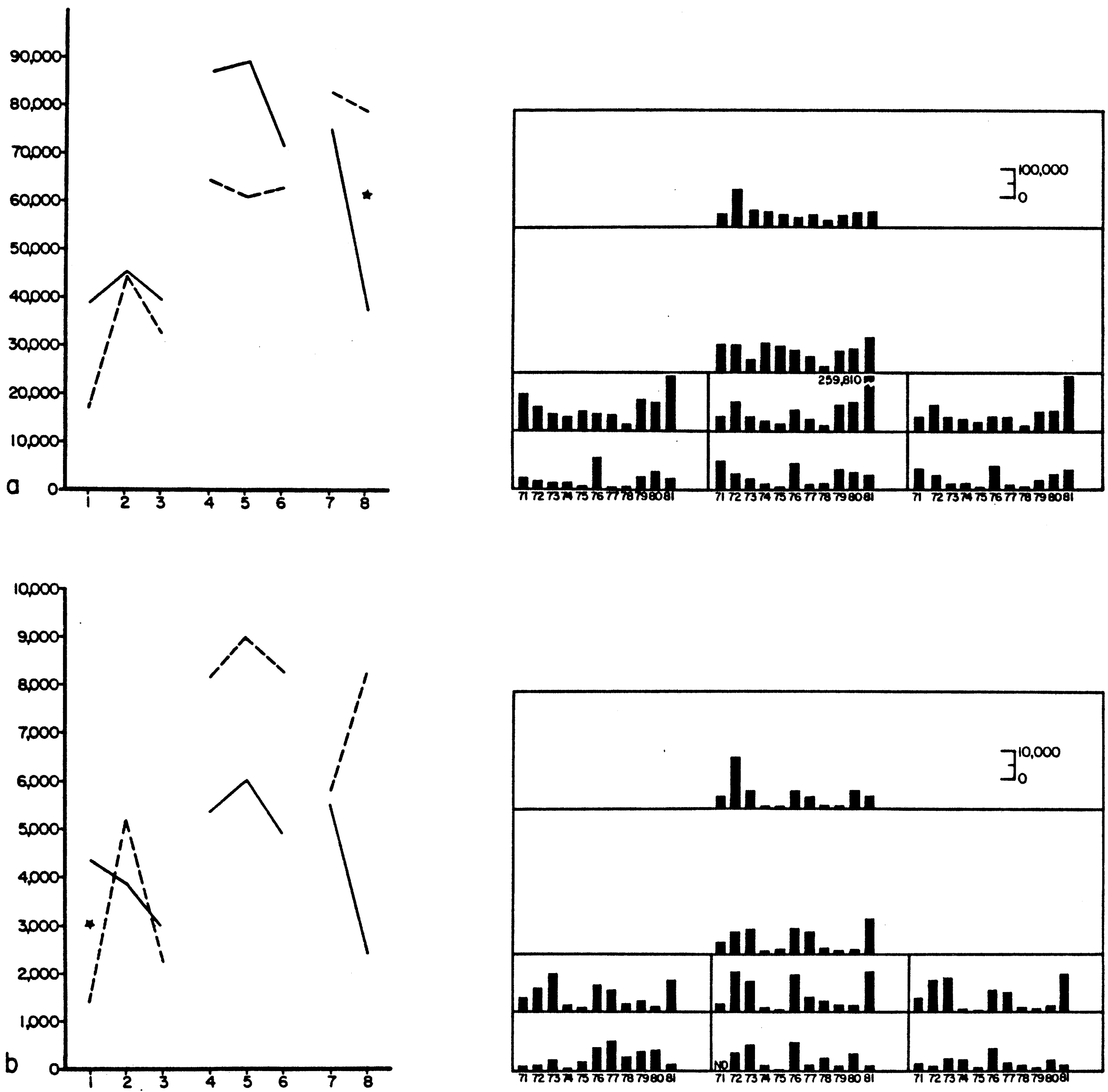


Fig. 35. The mean July preoperational (1971-1974) and operational (1975-1982) densities of zooplankton taxa by depth, zone, and year. The right side panel for each figure shows the mean densities for each year and depth zone in histograms. The left panel shows the mean preoperational (1971-1974) and operational period (1975-1982) (dashed and solid lines respectively) densities for each zone. Lines connect zones in the same depth grouping: inshore, middle, and inner and outer offshore zones. Stars indicate zones with significantly different preoperational and operational densities (Mann-Whitney U test $\alpha = 0.5$). ND = no data, TR = trace, Z = zero. a) Total zooplankton, b) copepod nauplii,

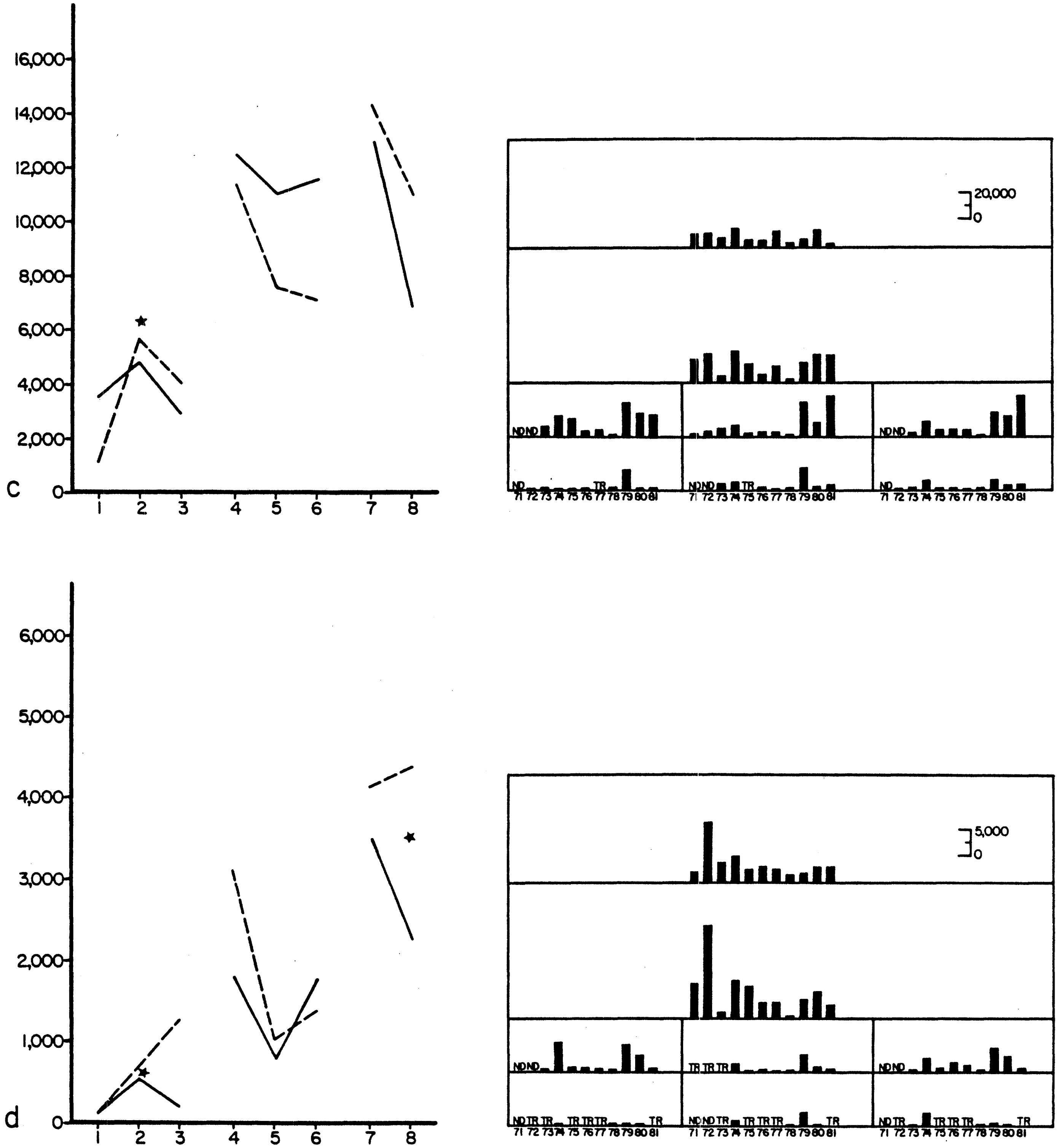


Fig. 35. Continued. c) cyclopoid copepods C1-C5, d) Cyclops spp. C6,

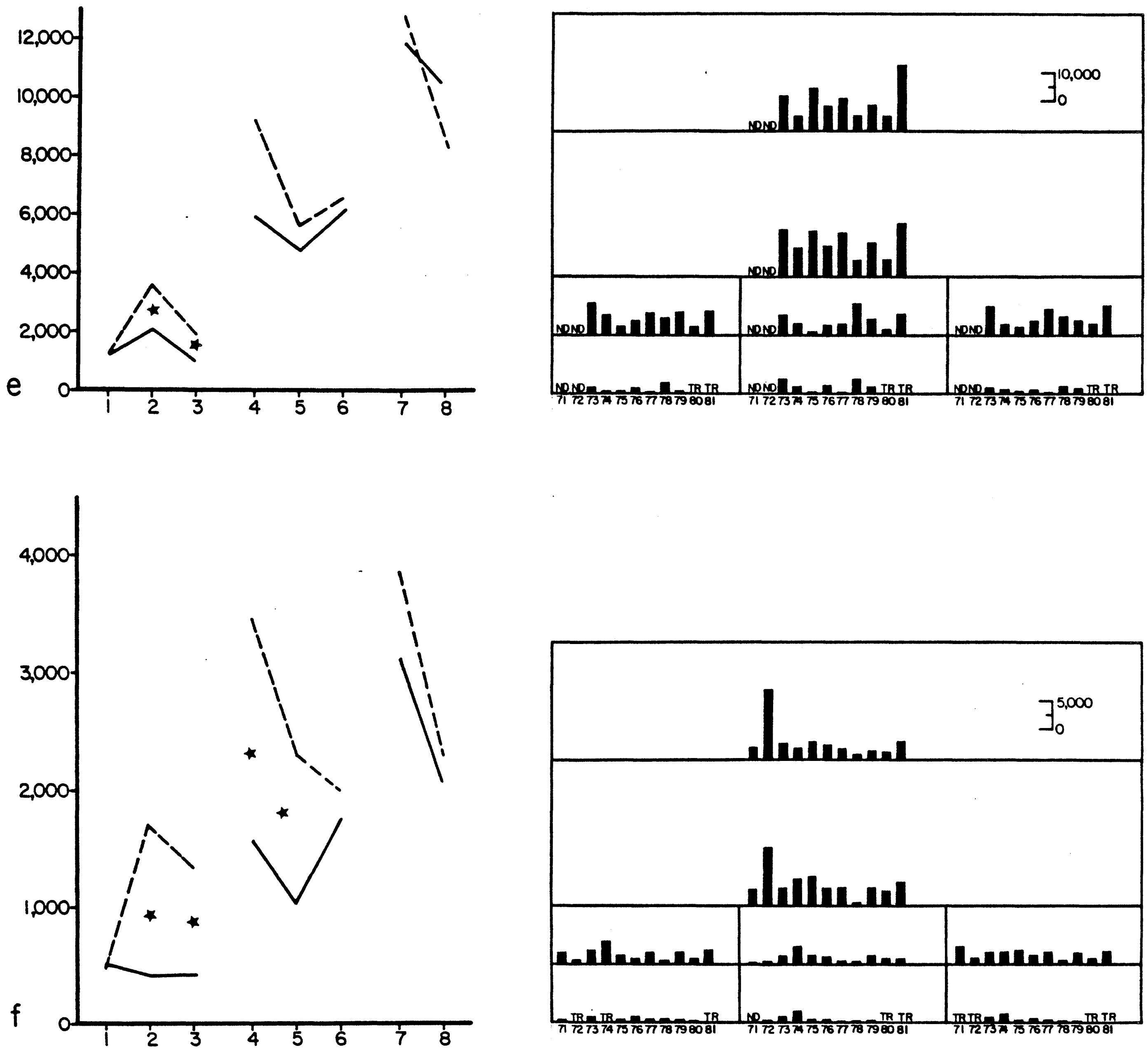


Fig. 35. Continued. e) Diaptomus spp. C1-C5, f) Diaptomus spp. C6,

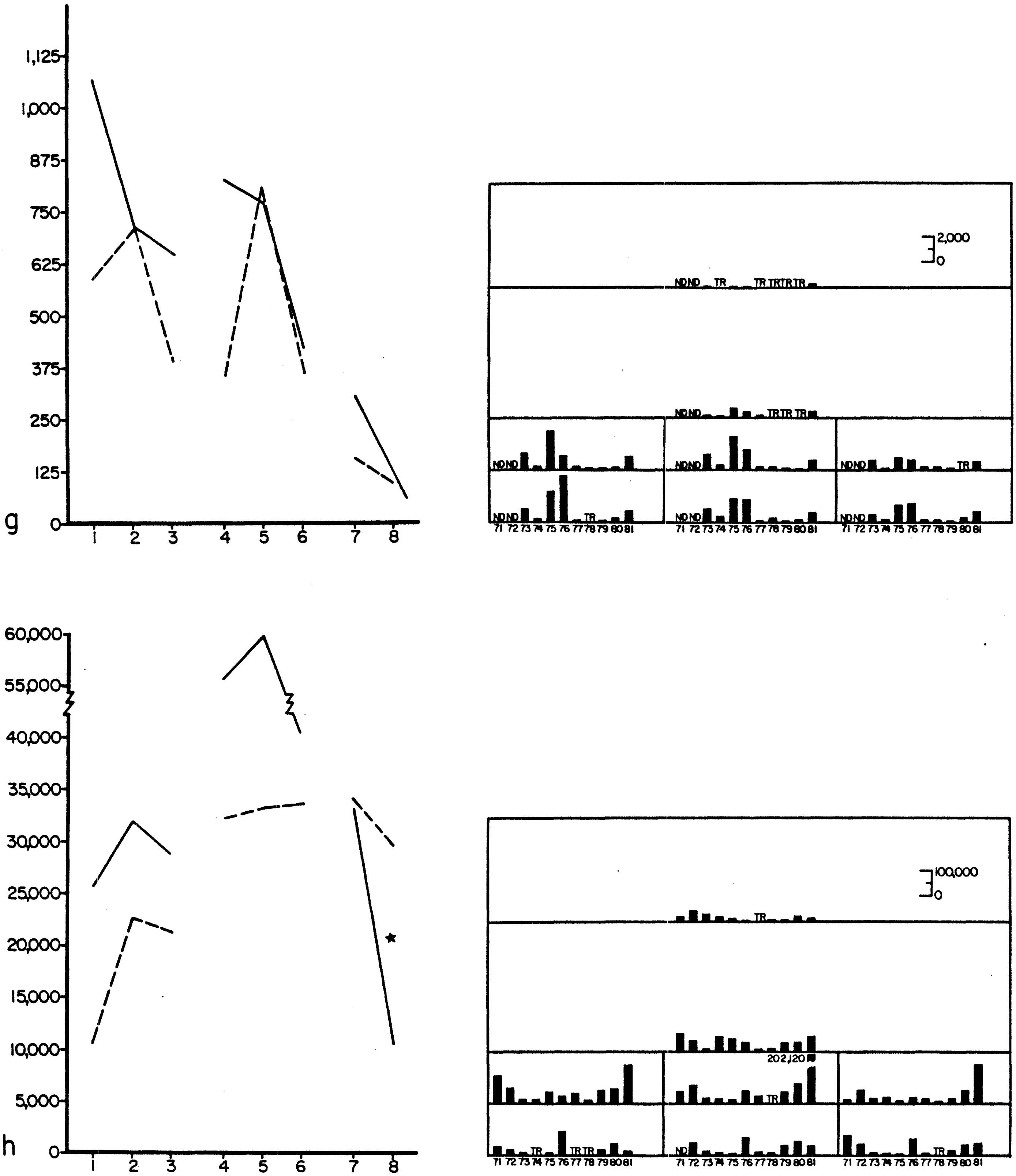


Fig. 35. Continued. g) Eurytemora affinis C1-C6, h) Bosmina longirostris,

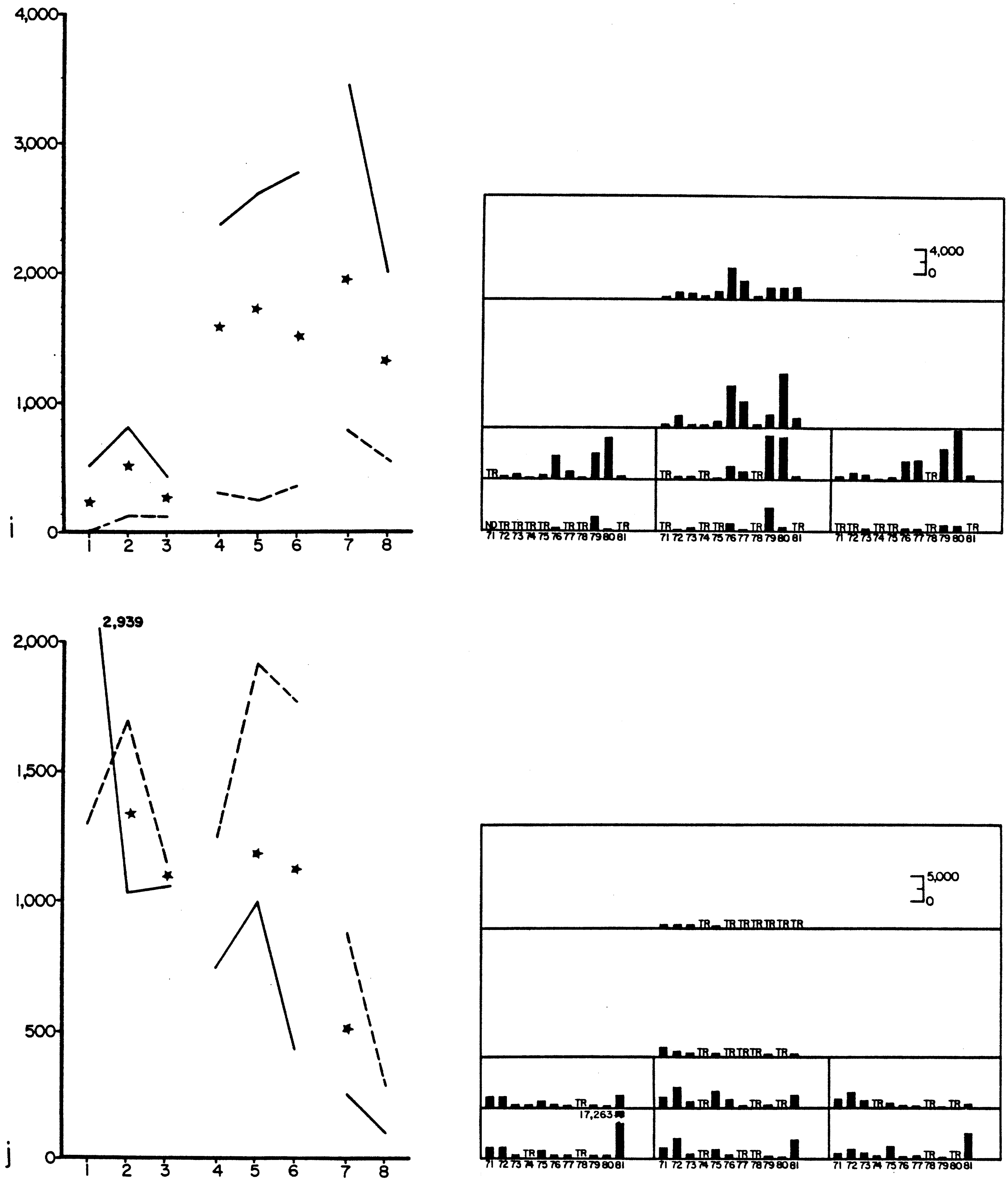


Fig. 35. Concluded. i) Daphnia spp., j) Asplanchna spp.

northern inshore zones. In both of these zones, immature diaptomids were approximately half as abundant in the operational period as in the preoperational period. A similar trend was observed for Diaptomus spp. adults (Fig. 35f). Adults were significantly (α=0.05) less abundant in the operational period than in the preoperational period in the inshore plume and northern zones (by a factor of two to three), and in the middle plume and southern zones (by a factor of less than one).

Eurytemora affinis copepodite densities were not significantly different, in any zone, between operational and preoperational periods (Fig. 35g). In general, operational abundances were higher than preoperational abundances. This may be attributed to the relatively large populations in 1975 and 1976. Populations in all other years were small.

Bosmina longirostris, the major cladoceran species of the July zooplankton assemblage, tended to be more abundant (by a factor of less than one) in the operational period than in the preoperational period in most zones of the survey grid; exceptions were the inshore northern zone and the inner and outer offshore zones (Fig. 35h). Differences were statistically significant (α=0.05) only in the outer offshore zone (Table 8) where preoperational densities were approximately three times greater than operational densities.

Daphnia spp., the second most abundant cladoceran taxon, occurred in significantly (α=0.05) higher densities in the operational period (Fig. 35i) than in the preoperational period in all eight zones of the survey grid. Differences were large, ranging from a factor of about four to more than twenty.

The only rotifer taxon analyzed was the predaceous Asplanchna. With the exception of the southern inshore zone, abundances were less in the operational period than in the preoperational period (Fig. 35j). Statistically significant (α=0.05) differences were detected in the inshore plume and northern zones, the middle plume and northern zones, and in the inner offshore zone. Differences in abundance ranged from a factor of less than one to nearly four.

Statistical Comparison of October Preoperational with Operational (1975-1981) Abundances

A total of twelve taxa were analyzed for preoperational and operational density differences in October (Table 9). Nine of the twelve taxa examined exhibited statistically (α=0.05) significant differences between preoperational and operational zone mean densities. Only immature and adult Diaptomus spp. copepodites, and cladocerans exhibited similar preoperational and operational densities. However, at the genus level, cladocerans did vary significantly in abundance between the two time periods.

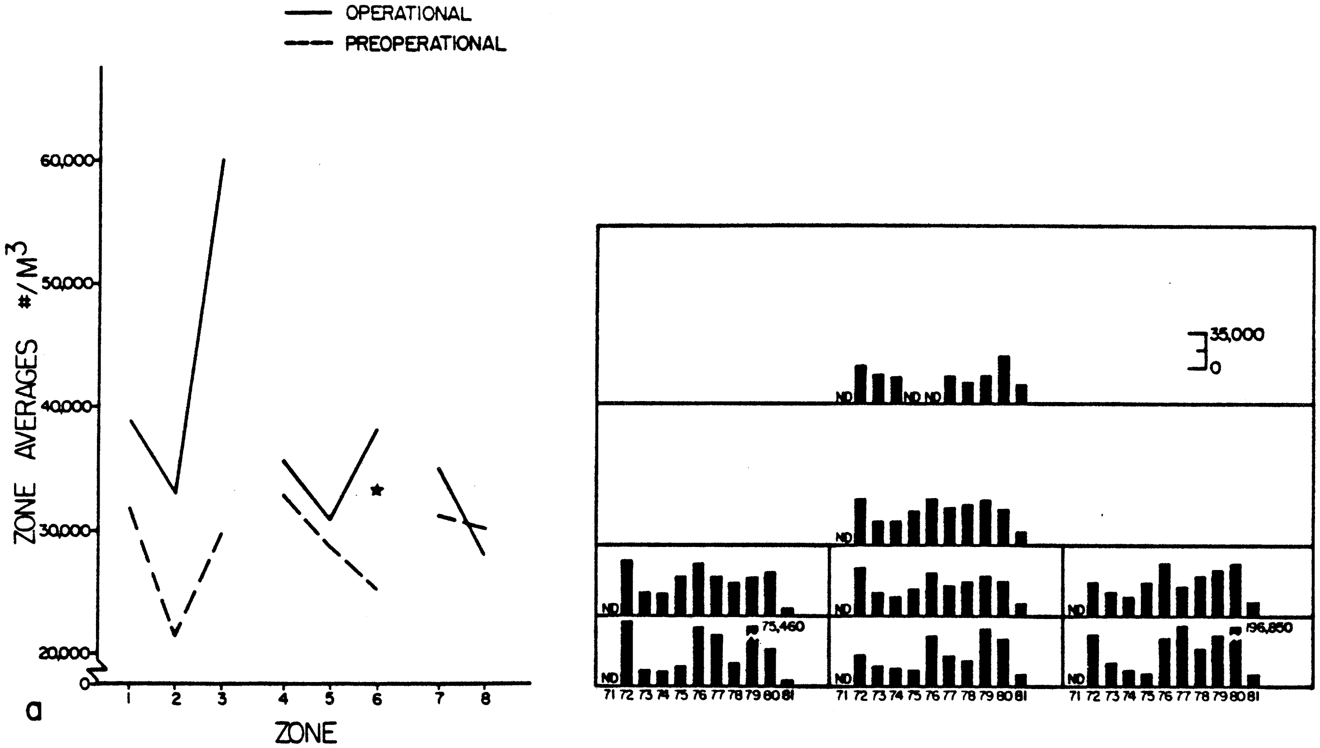
Total zooplankton were more abundant (by less than a factor of two) in the operational period than in the preoperational period with the exception of the outer offshore zone (Fig. 36a). Differences were statistically significant only for the northern middle zone (zone 6), where operational abundances were larger (by a factor of 1.5) than preoperational abundances (Table 9).

Copepod nauplii were up to twice as abundant in the operational period (Fig. 36b) as in the preoperational period. However, differences were statistically significant only for the inshore plume zone, the middle plume

Table 9. Results of the Mann-Whitney U tests comparing October preoperational and operational densities of twelve zooplankton taxa in each of eight zones. The preoperational period is 1972-74 or a subset ending in 1974, and the operational period is 1975-81. Stations in zone 8 were not sampled in 1975 or 1976 (see text). In column 1, results shown are from student's t-test analysis ($p < 0.05$) of the 3 inshore zones combined.

Taxon	Zone 1-3	1	2	3	4	5	6	7	8	Period
Order and Suborder Level										
Cladocerans	NS	NS	NS	NS	NS	NS	NS	NS	NS	72-81
Copepod nauplii	*	NS	*	NS	NS	*	*	*	NS	72-81
Cyclopoids (C1-C6)	NS	NS	NS	NS	NS	*	NS	NS	NS	72-81
Calanoids (C1-C6)	*	*	NS	NS	NS	NS	NS	NS	NS	72-81
Genus, Species, or Developmental Stage										
Bosmina longirostris	*	NS	*	NS	NS	*	*	*	NS	72-81
Eubosmina coregoni	*	NS	*	NS	NS	NS	NS	NS	*	72-81
Daphnia spp.	*	NS	*	*	NS	*	NS	NS	NS	72-81
Cyclopoids (C1-C5)	*	NS	NS	NS	*	*	NS	NS	NS	73-81
Cyclops spp. C6	*	NS	*	NS	NS	NS	NS	NS	NS	73-81
Diaptomus spp. (C1-C5)	NS	NS	NS	NS	NS	NS	NS	NS	NS	73-81
Diaptomus spp. C6	NS	NS	NS	NS	NS	NS	NS	NS	NS	73-81
Total zooplankton	*	NS	NS	NS	NS	NS	*	NS	NS	72-81

*significant difference, $\alpha = 0.05$.
NS not significant.



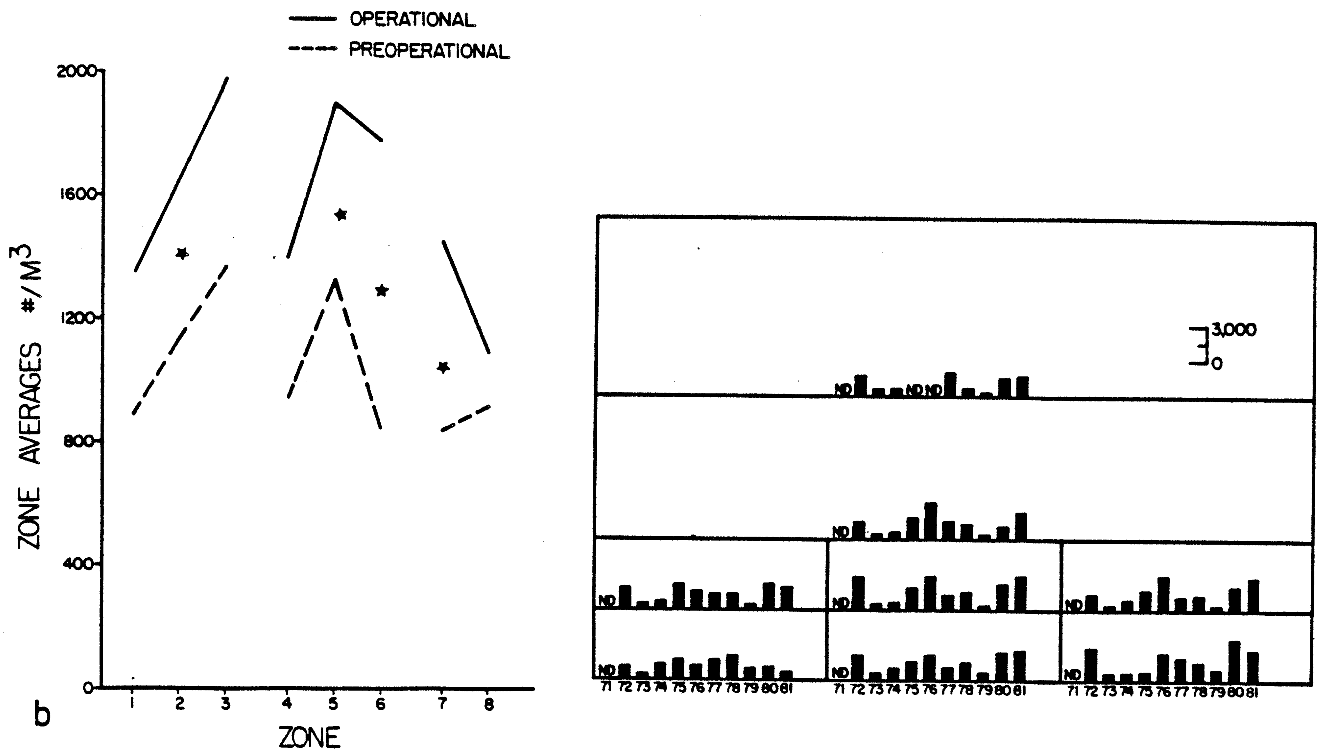
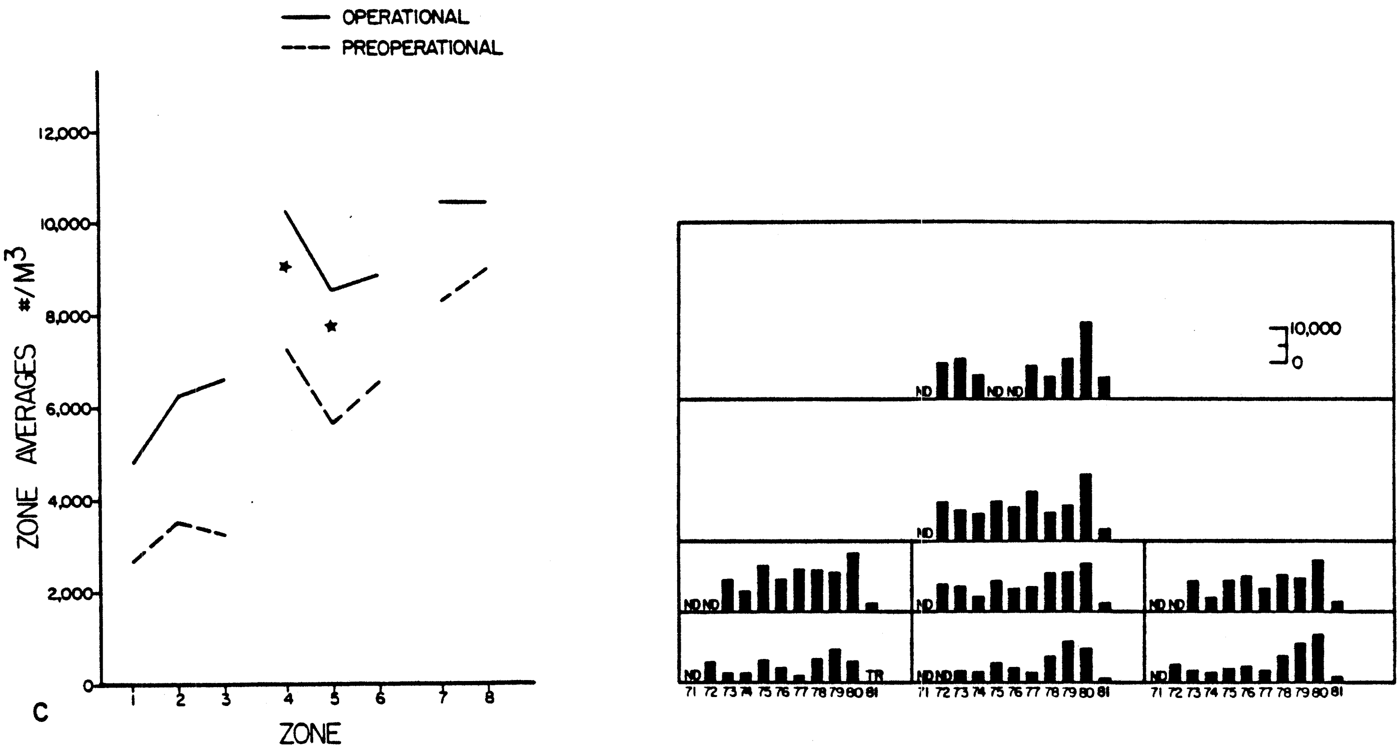


Fig. 36. The mean October preoperational (1971-1974) and operational (1975-1982) densities of zooplankton taxa by depth, zone, and year. The right side panel for each figure shows the mean densities for each year and depth zone in histograms. The left panel shows the mean preoperational (1971-1974) and operational (1975-1982) period (dashed and solid lines respectively) densities for each zone. Lines connect zones in the same depth grouping: inshore, middle, and inner and outer offshore zones. Stars indicate zones with significantly different preoperational and operational densities (Mann-Whitney U test $\alpha = 0.5$). ND = no data, TR = trace, Z = zero. a) Total zooplankton, b) copepod nauplii,



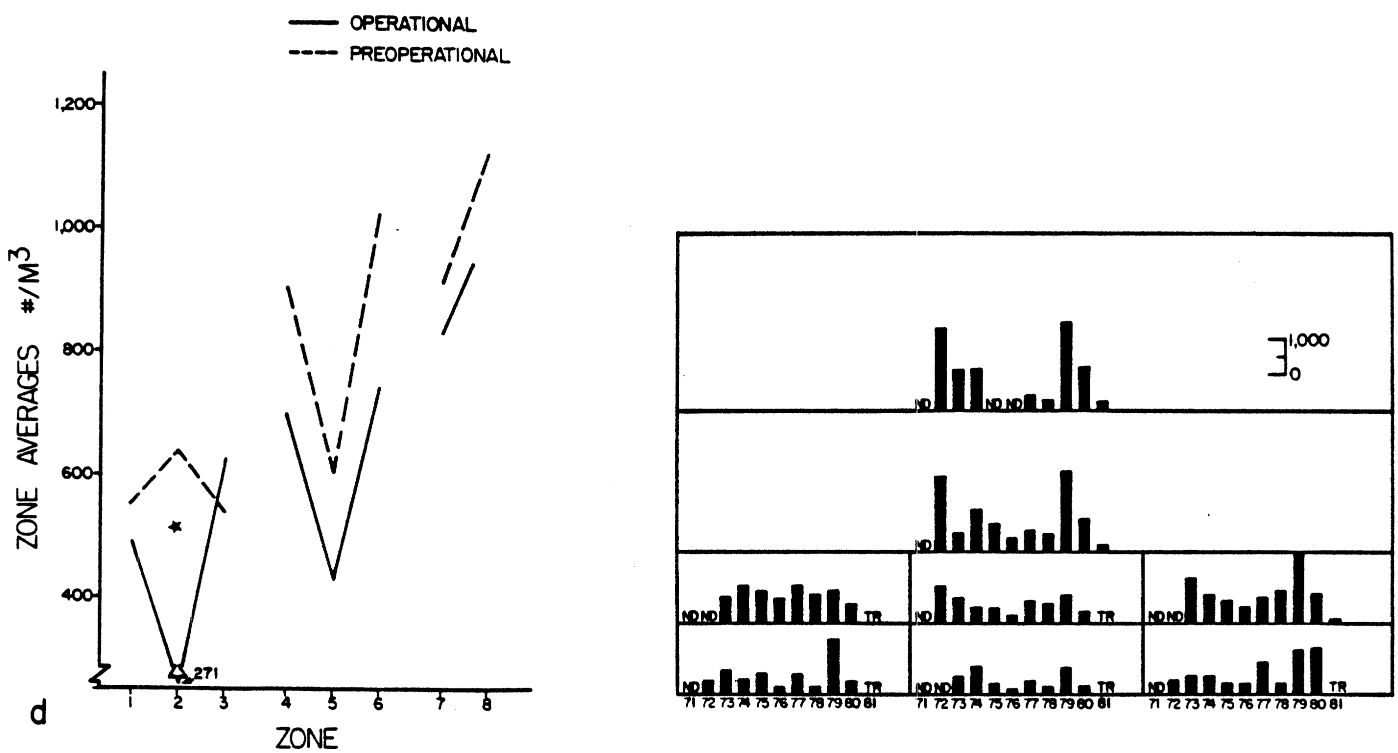
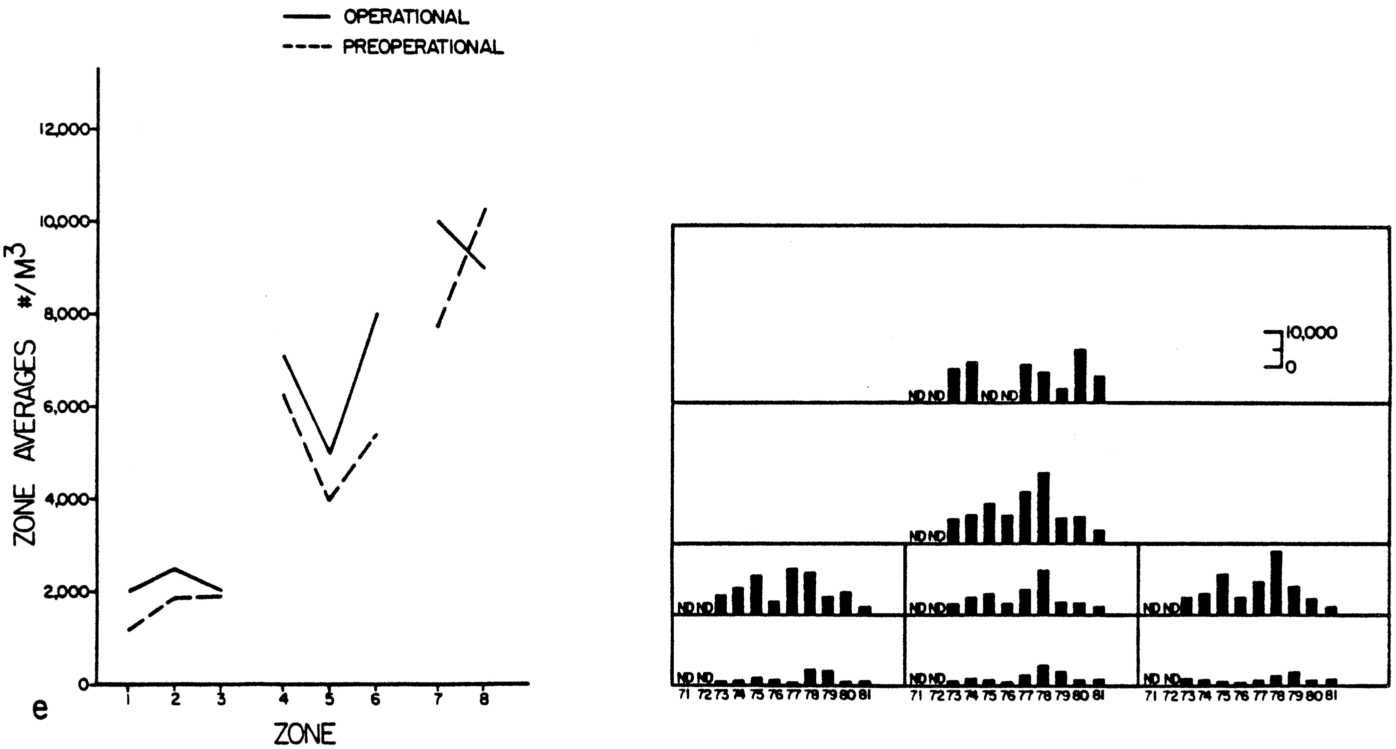


Fig. 36. Continued. c) cyclopoid copepods C1-C5, d) <u>Cyclops</u> spp. C6,



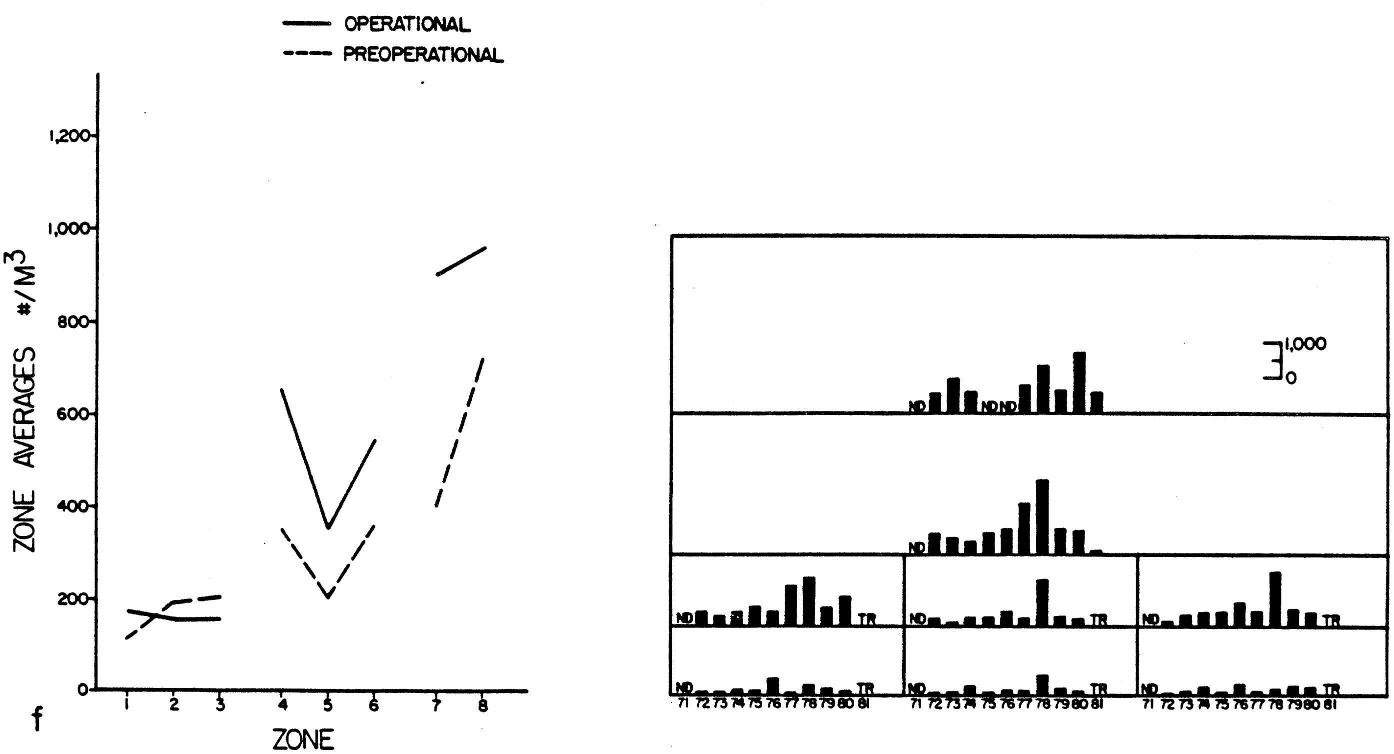
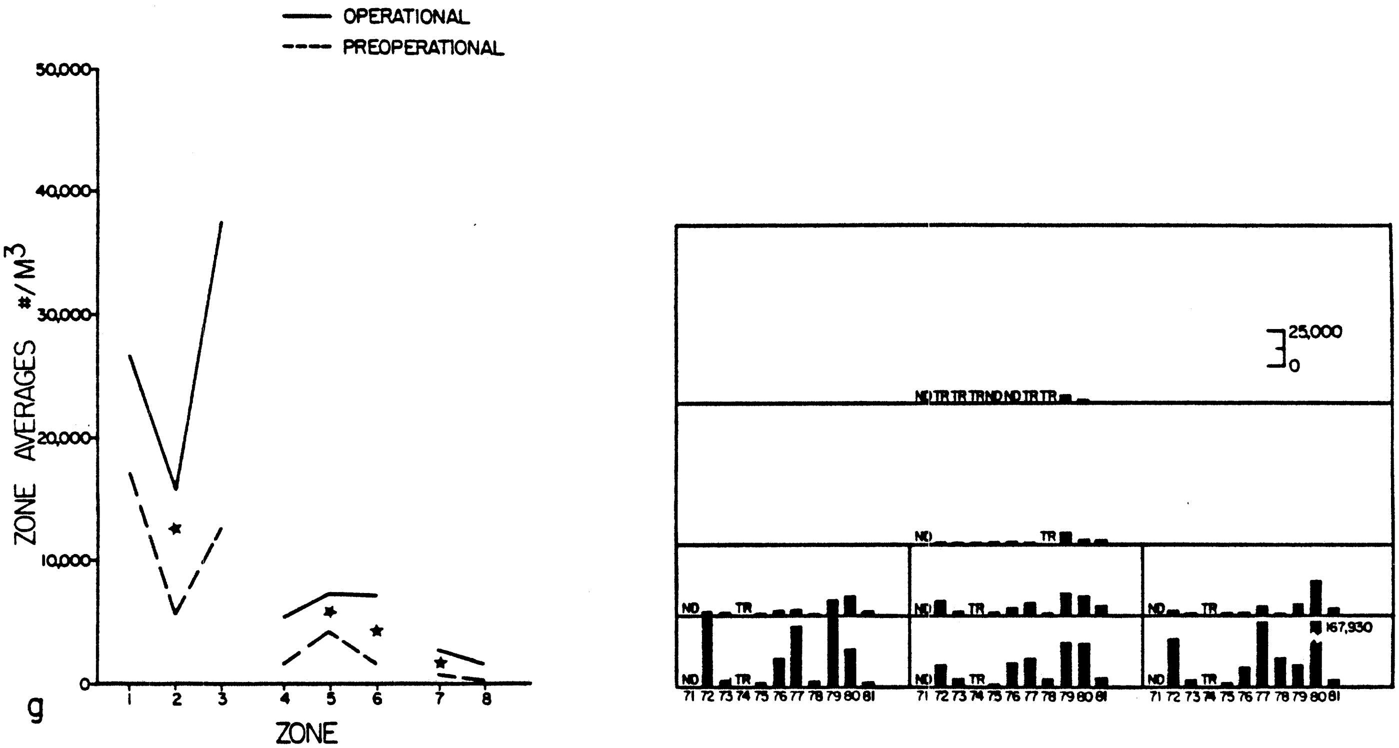


Fig. 36. Continued. e) Diaptomus spp. C1-C5, f) Diaptomus spp. C6,



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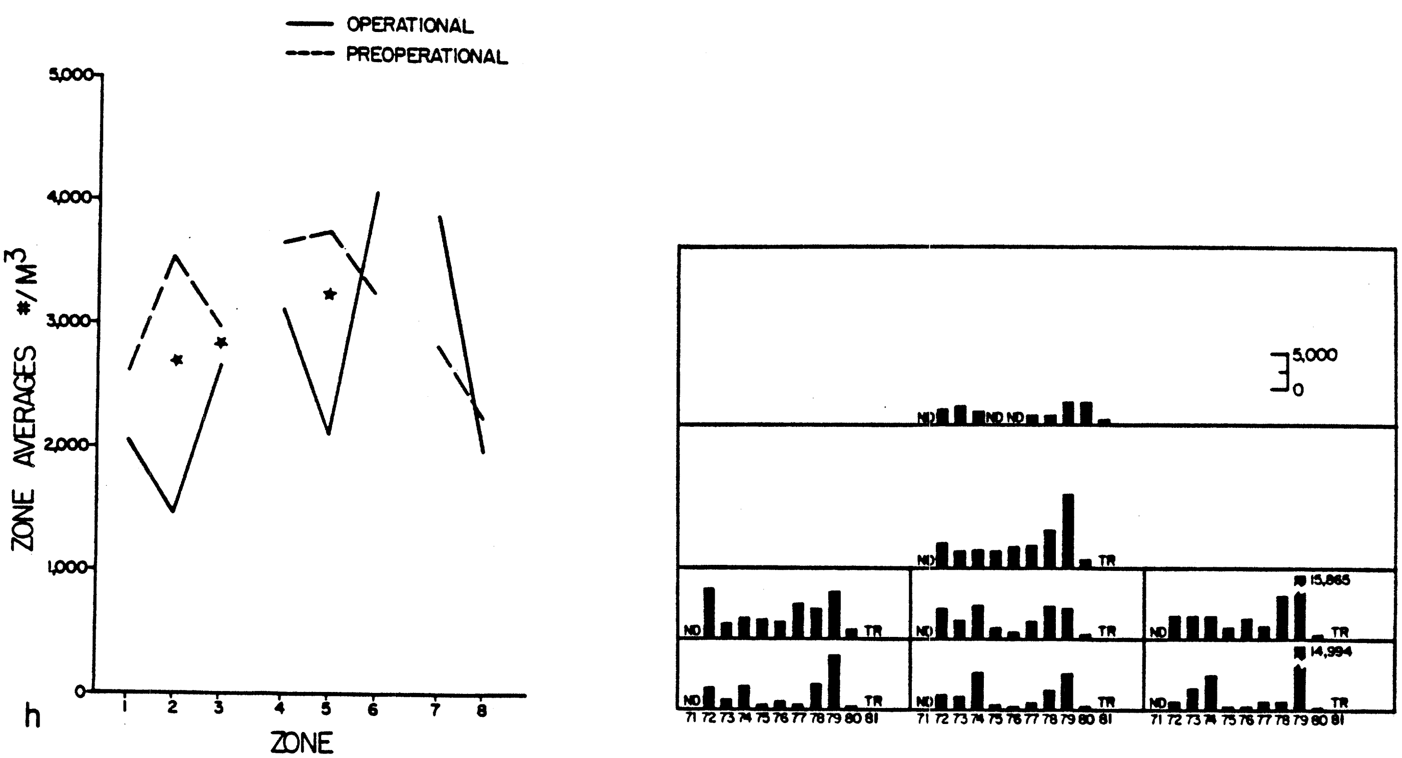


h

Fig. 36. Concluded. g) Bosmina longirostris, h) Daphnia spp.

and middle northern zones, and the inner offshore zone. Similar magnitudes of change were observed in plume and control zones (Table 9).

Although immature Cyclops spp. copepodites were less abundant in October 1981 than in previous operational years (Fig. 36c), operational zone means (1975-1981) were greater than preoperational; differences were less than a factor of two. Statistically significant (α=0.05) differences were detected in the southern and plume middle zones (Table 5). Cyclops bicuspidatus thomasi adults were less abundant in the operational period (by less than a factor of two) with the exception of the northern inshore zone (Fig. 36d). However, it was only in the inshore plume zone that these differences were statistically significant.

Abundances of adult and immature Diaptomus spp. copepodites were not significantly different in preoperational vs. operational years. Generally, abundances of these groups were higher during operational years (Figs. 36e and 36f; Table 9).

The cladoceran Bosmina longirostris occurred in higher densities (by factors ranging from less than one to more than three) in the operational than in the preoperational period (Fig. 36g). Differences were statistically significant in the inshore plume zone, the middle plume and northern zones, and the inner offshore zone (Table 9). Despite preoperational-operational differences, B. longirostris abundances in 1981 were lower than in other operational years.

Daphnia spp. occurred in relatively low densities (Fig. 36h) in 1981. With the exception of the northern middle zone and the inner offshore zone, densities were lower (generally less than a factor of two) in the operational period than in the preoperational period. Differences were statistically

significant (α=0.05) only for the inshore plume and northern zones (Table 9), with the greatest magnitude of change occurring in the plume zone.

With the exceptions of the northern inshore zone, the southern middle zone, and the outer offshore zone, Eubosmina coregoni was more abundant in the operational period than in the preoperational period (Fig. 36i). Differences were statistically significant for the three inshore zones, the middle plume zone, and the outer offshore zone. Preoperational versus operational differences in zone mean concentrations in the two plume zones were similar in magnitude to those observed in at least one control zone.

DISCUSSION

Comparison of the four years (1971-1974) of preoperational data with the eight years (1975-1982) of operational data indicates that there were many statistically significant differences in zooplankton abundances between the two time periods. These differences were not readily apparent by examining the time series plots (Fig. 30-33) of taxa abundances but were evident when comparisons were made across months.

During April, total zooplankton abundances in the inshore plume zone were significantly higher in the operational period (1975-1982) than the preoperational period (1971-1974). Copepod nauplii was the major taxon accounting for this increase. However, Limnocalanus macrurus and adult Diaptomus spp. also were significantly more abundant in the inshore plume zone in the operational period. Conversely, immature cyclopoid copepods were less abundant in the operational period. There was no evidence that these long-term changes in zooplankton abundances were related to any adverse effect of power plant operation. Similar magnitudes of change were observed in the

inshore and middle plume zones as in the north and south control zones. Factors affecting these changes in spring copepod populations remain under investigation.

Total zooplankton standing stocks in the inshore plume zone were similar during the July preoperational (1971-1974) and operational (1975-1981) cruises. The greatest changes were associated with *Diaptomus* spp. copepodites and *Asplanchna* spp., which were less abundant in the operational period, and with *Daphnia* spp., which were more abundant. These operational differences did not follow a consistent time trend. Rather, there were times in the operational period when zooplankton abundances were much higher (or lower) than observed during the preoperational period. There was no evidence that these preoperational and operational differences were related to power plant operation. Similar magnitudes of change were observed in the inshore and middle plume zones and in the north and south control zones. Factors affecting changes in summer copepod and *Daphnia* populations are discussed in Evans (1986), Evans and Jude (1986), and Scavia et al. (1986).

During October, total zooplankton occurred in similar preoperational (1972-1974) and operational (1975-1981) abundances in the inshore plume zone. Copepod nauplii and *Bosmina longirostris* were more abundant in the operational period while adult *Cyclops* spp. and *Daphnia* spp. were less abundant. These preoperational-operational differences did not appear to be due to plant operation as similar magnitudes of change were observed in the plume zones and in the north and south control zones. Factors affecting changes in *Daphnia* populations are discussed in Evans and Jude (1986).

Overall, there was no evidence from any aspect of our survey cruise studies that power plant operation had any adverse impact (spatial or

temporal) on zooplankton community structure in the thermal plume region. Preoperational-operational differences in abundance did occur and some of the factors accounting for such changes have been identified (Evans 1986, Evans and Jude 1986, Scavia et al. 1986). Other changes remain under investigation.

A large body of literature accumulated over the 1960s and early 1970s documenting the effects of thermal discharges on zooplankton communities in a number of fresh, brackish, and marine habitats. In general, few effects were detected, and thus thermal pollution no longer is an active area of research although site-specific monitoring studies continue where required.

Power plant operation can adversely affect zooplankton communities in a limited number of situations. The most obvious occurs when a large fraction of zooplankton are killed by plant passage and then are discharged into a relatively small volume of water. Such adverse effects have been detected in rivers and cooling ponds (Zhitenjowa and Nikanorow 1972, Davies and Jensen 1974, Carpenter et al. 1974).

Power plant operation may affect zooplankton communities if ambient waters are significantly heated over long time periods (days at least). Such effects have been detected in relatively small water bodies including experimental enclosures, an open area created in an ice-covered lake by a thermal discharge, and in small ponds (McMahon and Docherty 1975, Lanner and Pejler 1973, Patalas 1970). However, many researchers have failed to detect any obvious changes in zooplankton community structure in cooling ponds and small lakes (Heinle 1969, Whitehouse 1971, Mathur et al. 1980). No significant effects have been detected on large water bodies such as Lake Michigan (Industrial Bio-Test Laboratories, Inc. 1974a, 1974b, 1975, Texas Instruments Inc. 1975, Evans et al. 1978a, 1978b, 1982).

The Donald C. Cook Nuclear Plant minimizes damage inflicted on the zooplankton community by operating at a moderate ΔT and by utilizing subsurface discharge jets to rapidly cool and dilute condenser-passed water. The survey cruise program, by incorporating several years of preoperational and operational monitoring, was especially well designed to detect any plant-induced change in zooplankton community. As stated earlier, no significant changes were detected (Section 1; Evans 1981, 1984).

The lake survey program was sufficiently detailed to enable us to detect changes which did occur in zooplankton community structure over the course of the study. These changes began in 1978, but did not become pronounced until summer 1982 when the survey cruise program had been completed. A presentation of these changes is outside the scope of this report, which focuses on plant effects on the zooplankton community over the 1975 to May 1982 period. However, a brief summary of these changes is presented below.

In the offshore region, the most pronounced changes in zooplankton community structure occurred as larger taxa increased in abundance. In spring, these taxa included *Limnocalanus macrurus* and *Diaptomus sicilis*. These increases appear to be related to recent declines in alewife abundances. Similar changes were observed in the inshore region. In summer and autumn, the most pronounced changes in the offshore zooplankton community structure were associated with the increased abundance of larger *Daphnia* species (including *D. pulicaria*). Such changes are attributed to decreased predation pressure exerted on the total zooplankton community by declining populations of alewives and an intensification of mysid (*Mysis relicta*) predation pressures on smaller *Daphnia* species (Evans and Jude 1986). While the early beginnings of these changes were observed over the 1978-1981 period, they did

not become distinct until summer 1982 when the lake survey program had been completed.

Long-term changes occurring in the summer and autumn inshore zooplankton community differed from those changes observed in the offshore. In general, there was little change in inshore zooplankton community structure during summer and autumn over the 1972 to May 1982 period. We hypothesize that although alewife abundances declined over the 1978 to 1982 period, abundances remained sufficiently high in the inshore region to prevent the larger zooplankton from increasing substantially in abundance. Furthermore, bloaters (Coregonus hoyi) and yellow perch (Perca flavscens) increased in abundance as alewife populations declined. These facultative planktivores probably exerted increased predation pressure on the zooplankton community (Evans and Jude 1986, Evans 1986).

SECTION 3

THE EFFECTS OF PLANT PASSAGE ON ZOOPLANKTON MORTALITY

INTRODUCTION

Zooplankton experience various stresses during plant passage including thermal shock, mechanical abrasion, and toxic effects due to chlorination. As a result of these stresses, zooplankton may be temporarily immobilized (a form of shock), physiologically impaired, physically damaged, or killed. The actual degree of damage depends on the sensitivity of the organism, ambient conditions, and plant design and operating characteristics.

Zooplankton mortality studies were conducted as part of the monitoring studies at the Donald C. Cook Nuclear Plant. Mortality was investigated immediately after plant passage (0 hours), 6 hours after plant passage, and 24 hours after plant passage.

Mortality studies provided direct information on the effects of plant design and operating characteristics on zooplankton subjected to plant passage. Furthermore, these determinations allowed evaluations of the probable loss to the nearshore zooplankton community as a direct result of mortality due to plant passage. Thus, mortality studies complemented the field program. Mortalities at 0-hour were of most interest since these dead zooplankton are localized in the immediate discharge area. Zooplankton dying 6 hours and 24 hours after plant passage probably are transported kilometers away from the plant site. Dilution minimizes detectability of the effects of plant passage in these areas of the lake (Section 1; Evans and Sell 1983).

MATERIALS AND METHODS

Mortality Studies

Mortality studies were conducted once a month from January 1979 to May 1982, except in June 1979 when neither unit was operating. Discharge units were sampled only when that unit was in operation. Unit 1 was sampled 31 times over the 41 month period while Unit 2 was sampled 32 times.

Samples were collected from the intake and discharge forebays (Fig. 37) with the Zaggot Trap sampler (Yocum et al. 1978). The sampler was first primed with water drawn by a Hale diaphragm pump. A carrier fitted with a 156 μm mesh net was lowered into the chamber to filter the water. The lid was clamped down and hose connections were arranged so that water was drawn from the intake or discharge forebay through a fixed pipe (7.6 cm diameter) to the sampler, and then through the pump. Sampling was conducted for 2 minutes with approximately 40 gallons (0.2 m^3) of water filtered each minute. Samples were collected in the intake forebay at grate location MTR 1-5 (5 m below the water surface) and from the discharge forebays of Units 1 and 2 (Fig. 37). Access was limited to a single location in each discharge forebay. Samples were generally collected within an hour of sunrise.

After sample collection, the mesh carrier was removed from the sampler, the outside washed down with water, and the contents of the plankton bucket transferred to a clean, formalin-free jar. Four samples were collected from each intake and discharge location. These replicate samples were taken to an on-site laboratory where each was subdivided as many times as necessary in a Folsom plankton splitter to give three subsamples containing several hundred zooplankton each. One subsample was immediately examined (0 hour), and the remaining two were placed in 1-L beakers containing approximately 500 mL of

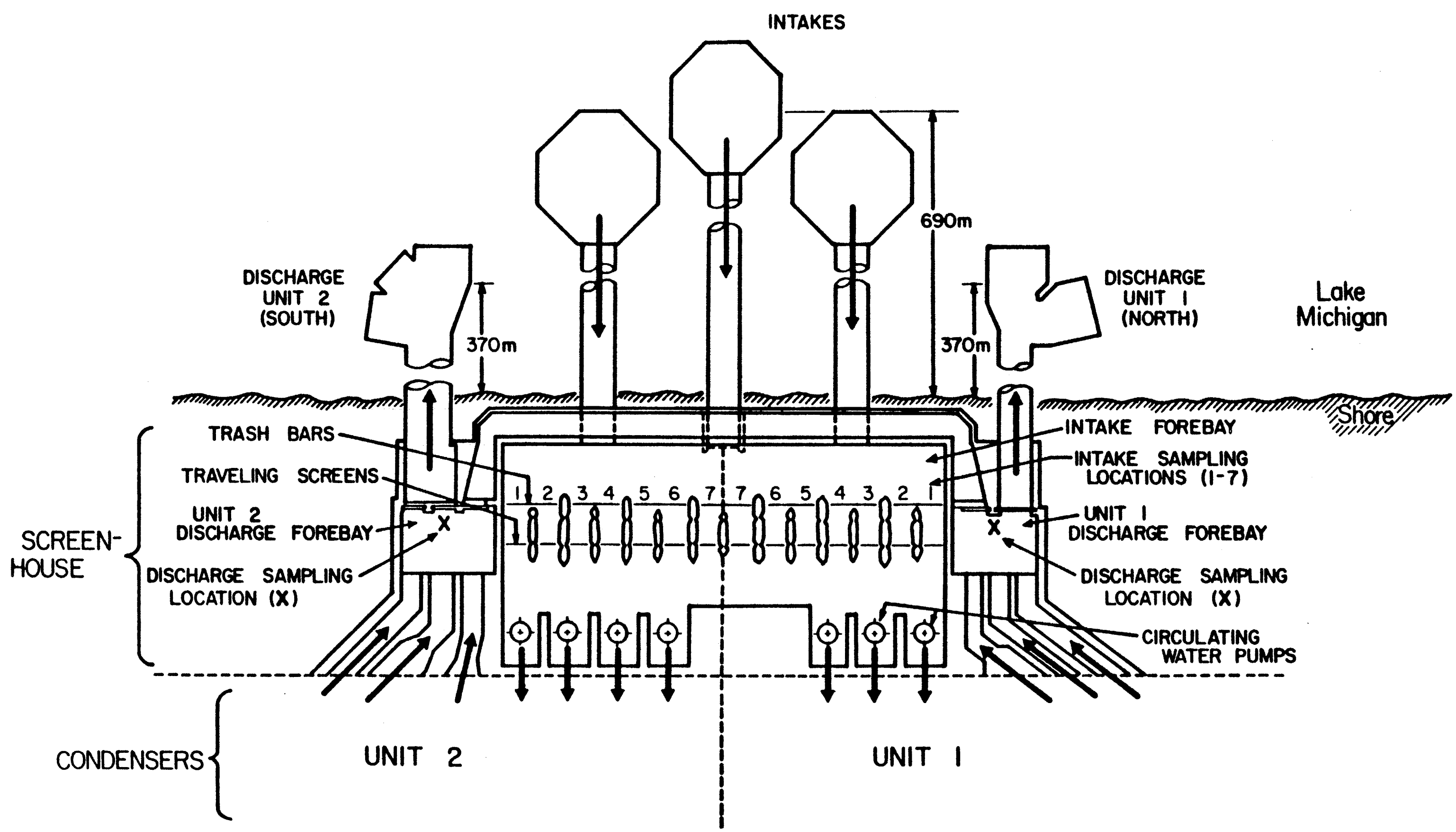


Fig. 37. A schematic view of the condenser cooling water system of the Cook Nuclear Plant.

filtered (156 μm) intake water, and maintained at the ambient lake water temperature in a Freas 815 incubator. All incubations were done in the dark. One subsample from each sample was examined 6 hours later and the remaining one was examined 24 hours later. Thus, a total of 12 subsamples were examined for each sampling location, representing 4 samples at each of 3 incubation times.

In the laboratory, each subsample was examined in a circular counting dish under a stereo dissecting microscope. Organisms which exhibited no visceral or appendicular movements even after gentle prodding were classified as "dead". Organisms were identified to suborder (nauplii), genus (Asplanchna spp., immature copepodites), or species (adult copepodites, cladocerans). Dead organisms were placed in a separate vial and preserved with Koechie's fluid. After complete examination of the sample, the remaining live zooplankton were preserved for later examination.

The percentage of dead zooplankton in each intake and discharge sample was calculated for all zooplankton taxa observed. The average taxa mortality for each sampling location/incubation series was calculated as the weighted mean taxa mortality of the appropriate four replicate values. Use of a weighted mean mortality corresponds to the use of a ratio estimator (Cochran 1977, Raj 1968). Weighted mean mortalities (ratio estimates) are preferred to simple means because samples and subsamples were composed of unequal numbers of zooplankton which were exposed, as groups, to the stresses of collection and laboratory handling (c.f. Cochran 1977). A simple example may clarify the difference between calculating simple and weighted means. Suppose the examination of four replicate samples for a rare species provided the following counts:

Sample 1: 1 out of 4 specimens of this taxon examined were dead;

Sample 2: 1 out of 3 specimens were dead;

Sample 3: 1 out of 1 specimen dead;

Sample 4: 2 out of 2 specimens dead.

The percentage dead in the four samples is 25, 33, 100, and 100%, respectively, and the simple mean percentage dead is (25+33+100+100)/4 = 64.5%. The weighted mean percentage is equal to the total number of animals dead (times 100) divided by the total number examined. In the example, the weighted mean fraction is (1+1+1+2)/(4+3+1+2) = 5/10 corresponding to a weighted mean percentage of 50%. If equal numbers of specimens are examined in each sample, then the simple and weighted mean values are identical.

The significance of intake vs. discharge mortalities on a monthly basis (Tables 10-12) were evaluated using the Smirnov upper-sided, two-sample test (Conover 1971); a significant value of $p \leq 0.05$ was used. The Smirnov test requires at least three observations per taxa from both intake and discharge. When a taxon was rare, the required three observations often were not available, and the test was not performed. In general, observations with less than five individuals were eliminated from the testing. Only those taxa which were numerically important during at least one season were analyzed. The taxa tested were: copepod nauplii, *Cyclops* spp. C1-C5, *Cyclops* spp. C6, *Diaptomus* spp. C1-C5 , *Diaptomus* spp. C6, *Bosmina longirostris*, *Eubosmina coregoni*, *Daphnia* spp., and total zooplankton.

To test whether discharge mortalities of the taxa were significantly greater ($p \leq 0.05$) than intake mortalities over the entire (1975-1982) operational period, a Wilcoxon sign-rank test (Conover 1971) was used. Ten animals per taxon was the lower limit for inclusion of an observation into the

Table 10. Results of the Smirnov one-sided two-sample tests comparing discharge and intake 0-hour sample mortalities for nine zooplankton taxa categories by month of collection. A — indicates insufficient data for the test, ns indicates discharge mortalities were not significantly ($p > 0.05$) higher than intake values, and * indicates discharge mortalities were significantly ($p < 0.05$) higher than intake values.

	1979 0 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	*	ns	-	-	-	-	*	ns	ns	ns	ns
Cyclops spp. C1-C5	ns	ns	*	-	-	-	-	ns	-	ns	ns	*
Cyclops spp. C6	ns	ns	*	-	-	-	-	-	-	ns	ns	ns
Diaptomus spp. C1-C5	ns	ns	-	-	-	-	-	*	*	ns	ns	ns
Diaptomus spp. C6	*	*	*	-	-	-	-	-	ns	ns	-	ns
Bosmina longirostris	-	-	-	-	-	-	-	ns	*	ns	*	ns
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	ns	-	ns
Daphnia spp.	-	-	-	-	-	-	-	ns	-	ns	ns	*
Total zooplankton	*	*	*	-	-	-	-	*	*	ns	ns	ns

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	*	ns	ns	ns	-	ns	-	ns	ns	-	-
Cyclops spp. C1-C5	ns	ns	*	ns	ns	-	ns	-	ns	ns	-	-
Cyclops spp. C6	ns	ns	*	ns	ns	-	*	-	ns	ns	-	-
Diaptomus spp. C1-C5	ns	ns	ns	*	ns	-	ns	-	ns	ns	-	-
Diaptomus spp. C6	ns	ns	*	ns	ns	-	ns	-	ns	ns	-	-
Bosmina longirostris	-	-	-	-	-	-	ns	-	ns	*	-	-
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	ns	-	-
Daphnia spp.	-	-	-	-	-	-	ns	-	-	ns	-	-
Total zooplankton	ns	ns	*	ns	ns	-	*	-	ns	ns	-	-

(continued)

Table 10. Continued.

	1980 0 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	ns	ns	ns	ns	-	-	ns	*	ns	ns	-
Cyclops spp. C1-C5	ns	ns	ns	ns	ns	-	-	ns	ns	ns	ns	ns
Cyclops spp. C6	ns	-	ns	ns	-	-	-	-	ns	ns	-	ns
Diaptomus spp. C1-C5	ns	-	ns	ns	ns	-	-	*	*	ns	ns	ns
Diaptomus spp. C6	ns	ns	ns	ns	-	-	-	-	-	-	-	*
Bosmina longirostris	-	-	-	-	-	-	-	ns	ns	ns	*	ns
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	ns	-
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	ns	ns
Total zooplankton	ns	ns	ns	ns	ns	-	-	ns	ns	ns	ns	ns

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	ns	ns	ns	ns	ns	*	*	ns	-	-
Cyclops spp. C1-C5	*	ns	ns	ns	ns	ns	ns	ns	*	*	-	-
Cyclops spp. C6	ns	ns	ns	ns	ns	ns	ns	-	ns	-	-	-
Diaptomus spp. C1-C5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	-
Diaptomus spp. C6	ns	ns	ns	ns	-	-	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	-	ns	*	ns	ns	ns	-	-
Eubosmina coregoni	-	-	-	-	-	-	-	ns	ns	ns	-	-
Daphnia spp.	-	-	-	-	-	ns	ns	ns	-	-	-	-
Total zooplankton	*	ns	ns	ns	ns	ns	*	ns	ns	ns	-	-

(continued)

Table 10. Continued.

	1981 0 - hr Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	ns	ns	ns	ns	-	-	ns	*	-	-	ns
Cyclops spp. C1-C5	ns	ns	-	-	ns	-	-	ns	ns	-	-	ns
Cyclops spp. C6	-	-	-	ns	ns	-	-	-	-	-	-	ns
Diaptomus spp. C1-C5	-	-	ns	ns	ns	-	-	ns	ns	-	-	ns
Diaptomus spp. C6	ns	ns	ns	ns	ns	-	-	ns	ns	-	-	ns
Bosmina longirostris	-	-	-	-	ns	-	-	ns	ns	-	-	ns
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	-	ns
Daphnia spp.	-	-	-	-	-	-	-	-	ns	-	-	-
Total zooplankton	ns	ns	ns	ns	ns	-	-	ns	ns	-	-	ns

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	-	-	-	ns	ns	*	ns	-	*	ns
Cyclops spp. C1-C5	ns	ns	-	-	-	ns	ns	ns	ns	-	ns	ns
Cyclops spp. C6	-	-	-	-	-	ns	-	-	-	-	ns	ns
Diaptomus spp. C1-C5	-	-	-	-	-	ns	-	ns	ns	-	ns	ns
Diaptomus spp. C6	ns	ns	-	-	-	-	-	ns	ns	-	ns	ns
Bosmina longirostris	-	-	-	-	-	ns	ns	*	ns	-	ns	*
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	ns	ns
Daphnia spp.	-	-	-	-	-	-	-	-	ns	-	-	-
Total zooplankton	ns	ns	-	-	-	ns	ns	*	ns	-	ns	*

(continued)

Table 10. Concluded.

	1982 0 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	-	ns	ns	*	-	-	-	-	-	-	-
Cyclops spp. C1-C5	ns	-	ns	-	-	-	-	-	-	-	-	-
Cyclops spp. C6	ns	-	-	-	-	-	-	-	-	-	-	-
Diaptomus spp. C1-C5	ns	-	ns	*	*	-	-	-	-	-	-	-
Diaptomus spp. C6	ns	-	ns	*	ns	-	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	ns	-	-	-	-	-	-	-
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	-	-
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	-	-
Total zooplankton	ns	-	ns	ns	*	-	-	-	-	-	-	-

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	ns	*	ns	-	-	-	-	-	-	-
Cyclops spp. C1-C5	ns	ns	ns	-	-	-	-	-	-	-	-	-
Cyclops spp. C6	ns	-	-	-	-	-	-	-	-	-	-	-
Diaptomus spp. C1-C5	ns	ns	ns	*	ns	-	-	-	- -	-		
Diaptomus spp. C6	ns	ns	ns	ns	ns	-	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	ns	-	-	-	-	-	-	-
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	-	-
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	-	-
Total zooplankton	ns	ns	ns	*	ns	-	-	-	-	-	-	-

Table 11. Results of the Smirnov one-sided two-sample tests comparing discharge and intake 6-hour sample mortalities for nine zooplankton taxa categories by month of collection. A — indicates insufficient data for the test, ns indicates discharge mortalities were not significantly ($p > 0.05$) higher than intake values, and * indicates discharge mortalities were significantly ($p < 0.05$) higher than intake values.

1979 6 - hr

Discharge 1

	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	*	-	-	-	-	-	*	ns	ns	ns	ns
Cyclops spp. C1-C5	ns	ns	ns	-	-	-	-	*	ns	*	ns	ns
Cyclops spp. C6	ns	-	ns	-	-	-	-	-	-	ns	ns	ns
Diaptomus spp. C1-C5	ns	ns	ns	-	-	-	-	*	*	ns	ns	*
Diaptomus spp. C6	ns	ns	ns	-	-	-	-	-	ns	ns	-	ns
Bosmina longirostris	-	-	-	-	-	-	-	ns	ns	ns	ns	ns
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	ns	-	-
Daphnia spp.	-	-	-	-	-	-	-	*	-	ns	ns	ns
Total zooplankton	ns	ns	*	-	-	-	*	*	ns	ns	ns	

Discharge 2

	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	ns	-	ns	ns	-	ns	-	ns	ns	-	-
Cyclops spp. C1-C5	ns	ns	ns	ns	ns	-	ns	-	ns	ns	-	-
Cyclops spp. C6	ns	-	*	ns	ns	-	ns	-	-	ns	-	-
Diaptomus spp. C1-C5	ns	ns	ns	ns	ns	-	ns	-	ns	ns	-	-
Diaptomus spp. C6	ns	ns	ns	ns	ns	-	ns	-	ns	ns	-	-
Bosmina longirostris	-	-	-	-	-	-	ns	-	*	ns	-	-
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	ns	-	-
Daphnia spp.	-	-	-	-	-	-	ns	-	-	ns	-	-
Total zooplankton	ns	ns	*	ns	ns	-	ns	-	*	ns	-	-

(continued)

Table 11. Continued.

	1980 6 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	ns	ns	ns	-	-	ns	ns	ns	ns	-
Cyclops spp. C1-C5	ns	ns	ns	ns	ns	-	-	ns	ns	ns	ns	ns
Cyclops spp. C6	ns	-	ns	ns	-	-	-	-	-	-	-	*
Diaptomus spp. C1-C5	ns	ns	ns	ns	ns	-	-	ns	ns	ns	ns	ns
Diaptomus spp. C6	ns	ns	ns	ns	-	-	-	-	-	-	ns	*
Bosmina longirostris	-	-	-	-	ns	-	-	ns	*	ns	ns	*
Eubosmina coregoni	-	-	-	-	-	-	-	-	ns	-	ns	ns
Daphnia spp.	-	-	-	-	-	-	-	-	ns	ns	ns	ns
Total zooplankton	ns	ns	ns	ns	ns	-	-	ns	ns	ns	ns	*

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	-
Cyclops spp. C1-C5	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	-	-
Cyclops spp. C6	ns	-	ns	ns	-	ns	-	-	-	-	-	-
Diaptomus spp. C1-C5	ns	ns	*	ns	ns	ns	ns	ns	-	ns	-	-
Diaptomus spp. C6	ns	ns	ns	*	-	ns	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	ns	ns	*	ns	ns	ns	-	-
Eubosmina coregoni	-	-	-	-	-	-	-	ns	ns	-	-	-
Daphnia spp.	-	-	-	-	-	-	ns	-	ns	ns	-	-
Total zooplankton	ns	ns	ns	ns	ns	ns	-	ns	ns	ns	-	-

(continued)

Table 11. Continued.

	1981 6 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	ns	ns	ns	-	-	ns	ns	ns	-	ns
Cyclops spp. C1-C5	ns	ns	ns	-	ns	-	-	-	ns	ns	-	ns
Cyclops spp. C6	-	-	-	ns	ns	-	-	-	ns	-	-	ns
Diaptomus spp. C1-C5	-	-	*	ns	ns	-	-	ns	ns	ns	-	ns
Diaptomus spp. C6	*	ns	ns	*	ns	-	-	ns	-	-	-	*
Bosmina longirostris	-	-	-	-	ns	-	-	ns	ns	ns	-	ns
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	-	ns
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	-	-
Total zooplankton	*	ns	*	ns	ns	-	-	ns	ns	ns	-	*

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	-	-	-	ns	ns	ns	ns	-	ns	ns
Cyclops spp. C1-C5	*	ns	-	-	-	*	ns	-	ns	-	ns	ns
Cyclops spp. C6	-	-	-	-	-	ns	-	-	ns	-	ns	ns
Diaptomus spp. C1-C5	-	-	-	-	-	ns	-	ns	ns	-	ns	ns
Diaptomus spp. C6	*	ns	-	-	-	-	-	ns	-	-	ns	-
Bosmina longirostris	-	-	-	-	-	ns	ns	ns	ns	-	*	ns
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	ns	ns
Daphnia spp.	-	-	-	-	-	ns	-	-	-	-	ns	-
Total zooplankton	*	ns	-	-	-	ns	ns	ns	ns	-	ns	ns

(continued)

Table 11. Concluded.

	1982 6 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	-	ns	*	*	-	-	-	-	-	-	-
Cyclops spp. C1-C5	ns	-	-	-	-	-	-	-	-	-	-	-
Cyclops spp. C6	ns	-	-	-	ns	-	-	-	-	-	-	-
Diaptomus spp. C1-C5	ns	-	-	ns	*	-	-	-	-	-	-	-
Diaptomus spp. C6	ns	-	ns	ns	ns	-	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	ns	-	-	-	-	-	-	-
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	-	-	-
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	-	-
Total zooplankton	*	-	ns	ns	*	-	-	-	-	-	-	-

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	ns	*	ns	-	-	-	-	-	-	-
Cyclops spp. C1-C5	ns	ns	-	-	-	-	-	-	-	-	-	-
Cyclops spp. C6	ns	-	-	-	-	-	-	-	-	-	-	-
Diaptomus spp. C1-C5	ns	ns	-	ns	ns	-	-	-	- -	-		
Diaptomus spp. C6	ns	ns	ns	*	ns	-	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	ns	-	-	-	-	-	-	-
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	-	-	-
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	-	-
Total zooplankton	ns	ns	ns	*	ns	-	-	-	-	-	-	-

Table 12. Results of the Smirnov one-sided two-sample tests comparing discharge and intake 24-hour sample mortalities for nine zooplankton taxa categories by month of collection. A -- indicates insufficient data for the test, ns indicates discharge mortalities were not significantly ($p > 0.05$) higher than intake values, and * indicates discharge mortalities were significantly ($p < 0.05$) higher than intake values.

1979 24 - hr

Discharge 1

	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	-	-	-	-	-	-	*	ns	ns	ns	-
Cyclops spp. C1-C5	ns	ns	ns	-	-	-	-	ns	-	ns	*	ns
Cyclops spp. C6	ns	-	ns	-	-	-	-	-	-	ns	ns	ns
Diaptomus spp. C1-C5	ns	ns	-	-	-	-	-	*	ns	ns	ns	ns
Diaptomus spp. C6	ns	ns	ns	-	-	-	-	-	ns	ns	ns	ns
Bosmina longirostris	-	-	-	-	-	-	-	ns	ns	ns	ns	ns
Eubosmina coregoni	ns	-	-	-	-	-	-	-	-	ns	ns	-
Daphnia spp.	-	-	-	-	-	-	-	ns	-	ns	ns	ns
Total zooplankton	ns	*	ns	-	-	-	-	*	ns	ns	ns	ns

Discharge 2

	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	-	-	ns	ns	-	ns	-	ns	ns	-	-
Cyclops spp. C1-C5	ns	ns	ns	ns	ns	-	*	-	-	ns	-	-
Cyclops spp. C6	ns	-	*	ns	ns	-	ns	-	-	ns	-	-
Diaptomus spp. C1-C5	ns	ns	-	ns	ns	-	*	-	ns	ns	-	-
Diaptomus spp. C6	ns	ns	ns	*	ns	-	*	-	ns	ns	-	-
Bosmina longirostris	-	-	-	-	-	-	ns	-	ns	ns	-	-
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	ns	-	-
Daphnia spp.	-	-	-	-	-	-	ns	-	-	ns	-	-
Total zooplankton	ns	ns	*	ns	ns	-	*	-	ns	ns	-	-

(continued)

Table 12. Continued.

	1980 24 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	ns	ns	ns	ns	-	-	ns	ns	ns	-	-
Cyclops spp. C1-C5	ns	ns	ns	*	ns	-	-	ns	ns	*	*	*
Cyclops spp. C6	ns	-	ns	ns	-	-	-	-	-	-	ns	ns
Diaptomus spp. C1-C5	ns	-	-	ns	ns	-	-	*	ns	*	*	ns
Diaptomus spp. C6	ns	ns	ns	ns	-	-	-	ns	-	-	ns	ns
Bosmina longirostris	-	-	-	-	ns	-	-	ns	ns	ns	ns	*
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	ns	-	ns
Daphnia spp.	-	-	-	-	-	-	-	-	-	-	ns	ns
Total zooplankton	ns	ns	*	ns	ns	-	-	ns	ns	*	*	*

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	ns	ns	ns	ns	ns	-	ns	ns	ns	-	-	-
Cyclops spp. C1-C5	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	-	-
Cyclops spp. C6	ns	-	ns	ns	-	ns	-	-	-	-	-	-
Diaptomus spp. C1-C5	ns	-	-	ns	ns	ns	ns	*	ns	ns	-	-
Diaptomus spp. C6	ns	ns	*	ns	-	-	-	-	-	-	-	-
Bosmina longirostris	-	-	-	-	ns	ns	ns	ns	ns	ns	-	-
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	ns	-	-
Daphnia spp.	-	-	-	-	-	ns	ns	-	-	-	-	-
Total zooplankton	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	-	-

(continued)

Table 12. Continued.

	1981 24 - hr											
	Discharge 1											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	ns	ns	ns	-	-	ns	ns	ns	-	ns
Cyclops spp. C1-C5	ns	ns	ns	-	ns	-	-	-	-	*	-	ns
Cyclops spp. C6	-	ns	-	ns	ns	-	-	-	-	ns	-	ns
Diaptomus spp. C1-C5	ns	ns	ns	ns	ns	-	-	-	*	*	-	ns
Diaptomus spp. C6	*	ns	ns	*	-	-	-	ns	-	-	-	ns
Bosmina longirostris	-	-	-	-	ns	-	-	*	ns	ns	-	ns
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	ns	-	ns
Daphnia spp.	-	-	-	-	-	-	-	-	ns	-	-	-
Total zooplankton	ns	ns	ns	*	ns	-	-	*	ns	*	-	ns

	Discharge 2											
	J	F	M	A	M	J	J	A	S	O	N	D
Copepod nauplii	-	ns	-	-	-	ns	ns	ns	ns	-	ns	ns
Cyclops spp. C1-C5	ns	ns	-	-	-	*	ns	-	-	-	ns	ns
Cyclops spp. C6	-	ns	-	-	-	ns	-	-	-	-	ns	ns
Diaptomus spp. C1-C5	-	-	-	-	-	*	-	-	ns	-	ns	ns
Diaptomus spp. C6	*	ns	-	-	-	-	-	ns	-	-	ns	ns
Bosmina longirostris	-	-	-	-	-	*	ns	ns	ns	-	ns	ns
Eubosmina coregoni	-	-	-	-	-	-	-	-	-	-	ns	ns
Daphnia spp.	-	-	-	-	-	ns	-	-	ns	-	-	-
Total zooplankton	*	ns	-	-	-	*	ns	ns	ns	-	ns	*

(continued)

Table 12. Concluded.

	J	F	M	A	M	J	J	A	S	O	N	D
					1982 24 - hr							
					Discharge 1							
Copepod nauplii	-	-	ns	*	*	-	-	-	-	-	-	-
<u>Cyclops</u> spp. C1-C5	*	-	ns	-	ns	-	-	-	-	-	-	-
<u>Cyclops</u> spp. C6	-	-	-	-	-	-	-	-	-	-	-	-
<u>Diaptomus</u> spp. C1-C5	ns	-	-	ns	ns	-	-	-	-	-	-	-
<u>Diaptomus</u> spp. C6	ns	-	ns	ns	ns	-	-	-	-	-	-	-
<u>Bosmina longirostris</u>	-	-	-	-	*	-	-	-	-	-	-	-
<u>Eubosmina coregoni</u>	-	-	-	-	-	-	-	-	-	-	-	-
<u>Daphnia</u> spp.	-	-	-	-	ns	-	-	-	-	-	-	-
Total zooplankton	*	-	ns	*	*	-	-	-	-	-	-	-

	J	F	M	A	M	J	J	A	S	O	N	D
					Discharge 2							
Copepod nauplii	-	ns	ns	*	ns	-	-	-	-	-	-	-
<u>Cyclops</u> spp. C1-C5	*	ns	ns	-	ns	-	-	-	-	-	-	-
<u>Cyclops</u> spp. C6	-	-	-	-	-	-	-	-	-	-	-	-
<u>Diaptomus</u> spp. C1-C5	ns	-	-	ns	ns	-	-	-	-	-	-	-
<u>Diaptomus</u> spp. C6	ns	ns	ns	ns	ns	-	-	-	-	-	-	-
<u>Bosmina longirostris</u>	-	-	-	-	*	-	-	-	- -	-		
<u>Eubosmina coregoni</u>	-	-	-	-	-	-	-	-	-	-	-	-
<u>Daphnia</u> spp.	-	-	-	-	-	-	-	-	-	-	-	-
Total zooplankton	ns	ns	ns	*	ns	-	-	-	-	-	-	-

11-year data set. All taxa were included in the analysis. Broad taxonomic categories (e.g., calanoid copepods C1-C6) were analyzed to determine which groups were major sources of mortality. Analyses of genus and species level data identified the more sensitive animals.

RESULTS

General Features of the 1979-1982 Mortality Study

Intake water temperatures during sampling varied from less than 1°C to 24°C while discharge temperatures were generally between 9 and 10 C° higher (Fig. 38). Discharge water temperatures generally exceeded 30 °C in the late summer (August and September) for both units. The plant pumped water at a rate varying from 0.55 to 0.85 x 10^6 gpm (2.1 to 3.2 x 10^3 m^3/min.) for Unit 1, and 0.75 to 1.18 x 10^6 gpm (2.9 to 4.5 x 10^3 m^3/min.) for Unit 2 during most sampling periods in which the units were operating (Fig. 39).

Zooplankton Mortality

Total Zooplankton

Total 0-hour zooplankton mortality in the intake for the 1979-1982 period ranged from 4 to 48%, with a simple mean of 13%. Highest mortality (48%) occurred in May 1979, when copepod nauplii and immature _Diaptomus_ spp. dominated the plankton (Fig. 40). Subsequent 0-hour mortalities exceeded 25% only in November 1979 and May 1980. In general, discharge mortalities followed intake mortality trends. Mean monthly 0-hour total zooplankton mortality values for Unit 1 discharge ranged from 6 to 32%, with a simple mean of 15%. The highest Unit 1 discharge mortality occurred in August 1979, when discharge temperature exceeded 34°C. Mortality at Unit 1 discharge reached

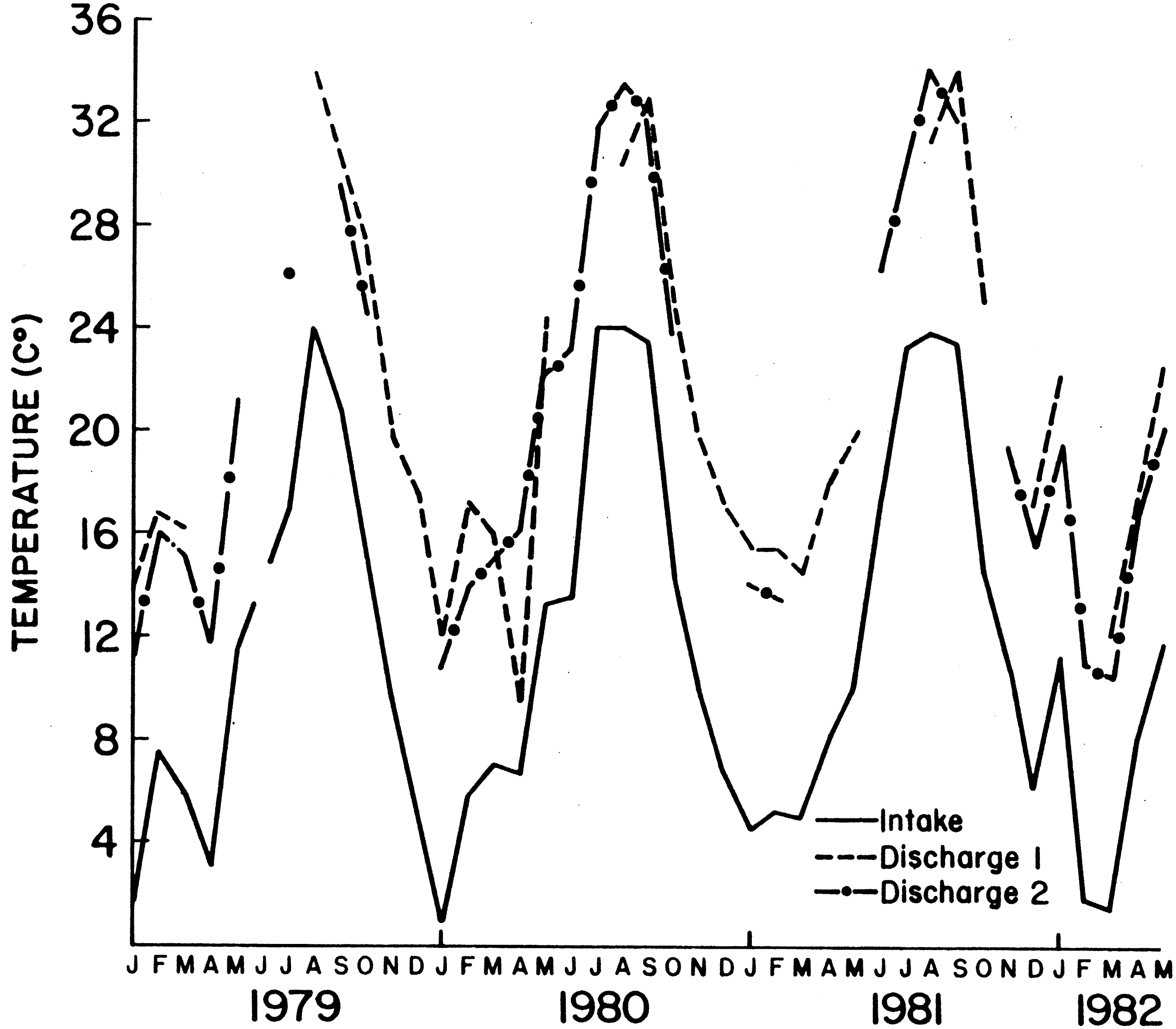


Fig. 38. Intake and discharge water temperatures for January 1979 to May 1982.

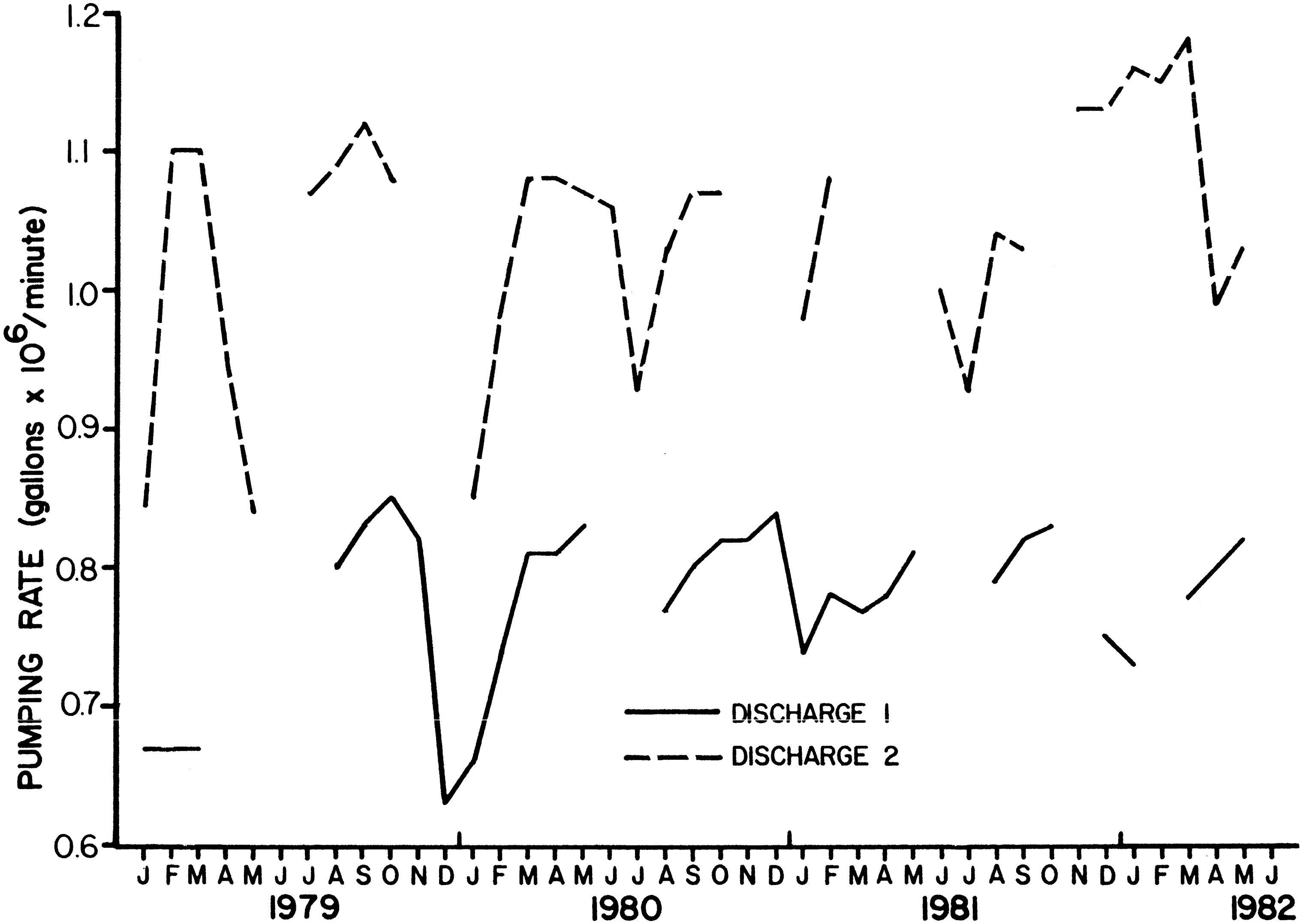


Fig. 39. Pumping rates (gallons x 10^6/minute) for Discharge 1 and Discharge 2 for January 1979 to May 1982.

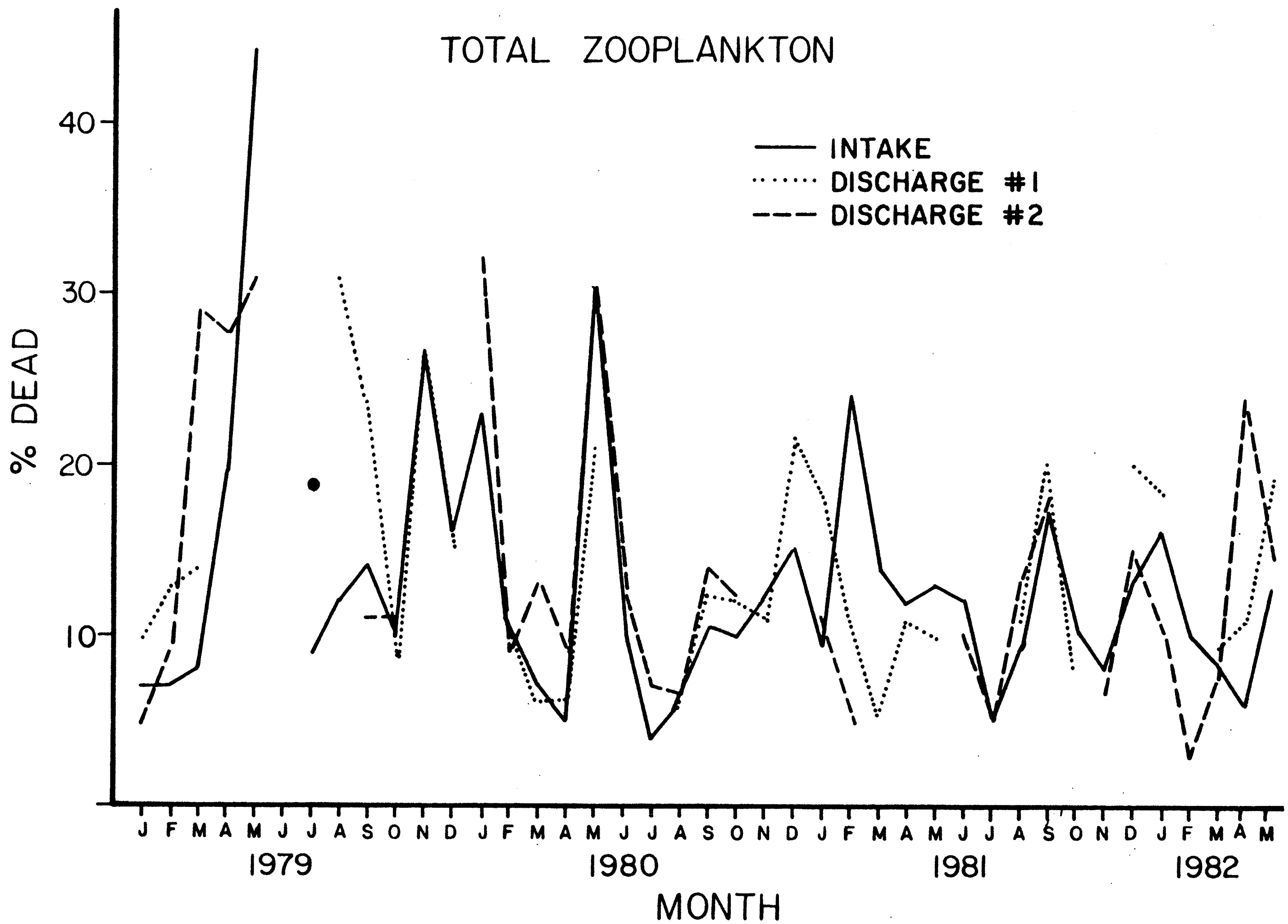


Fig. 40. Monthly mean mortality (0-hour) of total zooplankton.

25% during November 1979. Mortalities for Unit 2 discharge at 0-hour ranged from 3 to 33% and were highest in May 1979, and in January (33%) and May 1980 (30%).

Intake 6-hour mortalities ranged from 3 to 40%, with a simple mean of 13%, while 24-hour intake mortalities ranged from 4 to 30%, with a mean of 12%. Unit 1 discharge mortalities at 6-hours ranged from 4 to 39%, while 24-hour mortalities ranged from 3 to 33%. The 6- and 24-hour simple mean mortalities were 15 and 16%, respectively. For Unit 2 discharge, 6-hour mortalities ranged from 4 to 36%, with a mean of 13%, while 24-hour mortalities ranged from 7 to 34%, with a 14% simple mean.

Total zooplankton mortalities were significantly higher ($p < 0.05$) in discharge samples than in intake samples in 45 of the 184 month x incubation x discharge comparisons between January 1979 and May 1982 (Tables 10-12). Discharge mortalities significantly ($p < 0.05$) higher than intake mortalities occurred during all seasons. Therefore, significant mortality differences did not appear to be related to thermal regime. In 1979, statistically significant mortality differences occurred during six months: January, February, March, July, August, and September. In 1980, significant ($p = 0.05$) mortality differences were detected in January, March, July, October, November, and December. During 1981, January, March, April, May, August, October, and December were months of significantly higher discharge than intake mortalities, while in 1982 these months were January, April and May. Differences between intake and discharge mortalities generally were small.

Incubation duration had a minimal affect on total zooplankton mortality in these experiments. For the intake and each discharge, mean mortalities over the 1979-1982 period generally differed by less than 2% among the three

incubation times. For ease of graphical presentation and description, 0-hour mortalities will be highlighted for taxa which were numerical dominants during at least one season. Information, by month, on 6- and 24-hour incubation mortalities are available in Tables 11 and 12.

Copepod Nauplii

Numbers of copepod nauplii were highest in late spring and summer, although they were found in moderate densities in all seasons. Mean monthly 0-hour intake nauplii mortalities ranged from 0 to 63% during 1979-1982, with a simple mean of 13% (Fig. 41a). The highest intake mortalities occurred during May (50%), November (57%), and December 1979 (63%). The range (0 - 60%), simple mean (13%) and trends of 0-hour mortality values at Unit 1 discharge were similar to those of the intake. Unit 1 discharge mortality values exceeded 40% only during August (55%) and November (60%) 1979; during the remainder of the study, mortalities usually remained below 30%. The range of mortalities for Unit 2 discharge, 0-hour incubations (0 - 44%) was smaller than for unit 1 discharge, possibly because of the smaller data set for Unit 2 discharge. The highest Unit 2 discharge mortality (44%) occurred in April 1979.

Nauplii mortalities in Unit 1 discharge were significantly higher ($p < 0.05$) than intake mortalities in 20 discharge x incubation x month comparisons. Discharge mortalities were significantly higher than intake mortalities in August 1979, 1980, and 1981, and September 1980 and 1981, two months that accounted for 8 of the 20 significant comparisons (Tables 10-12). These were also months in which intake and discharge waters were warmest. High temperatures may have contributed to the mortalities during these months.

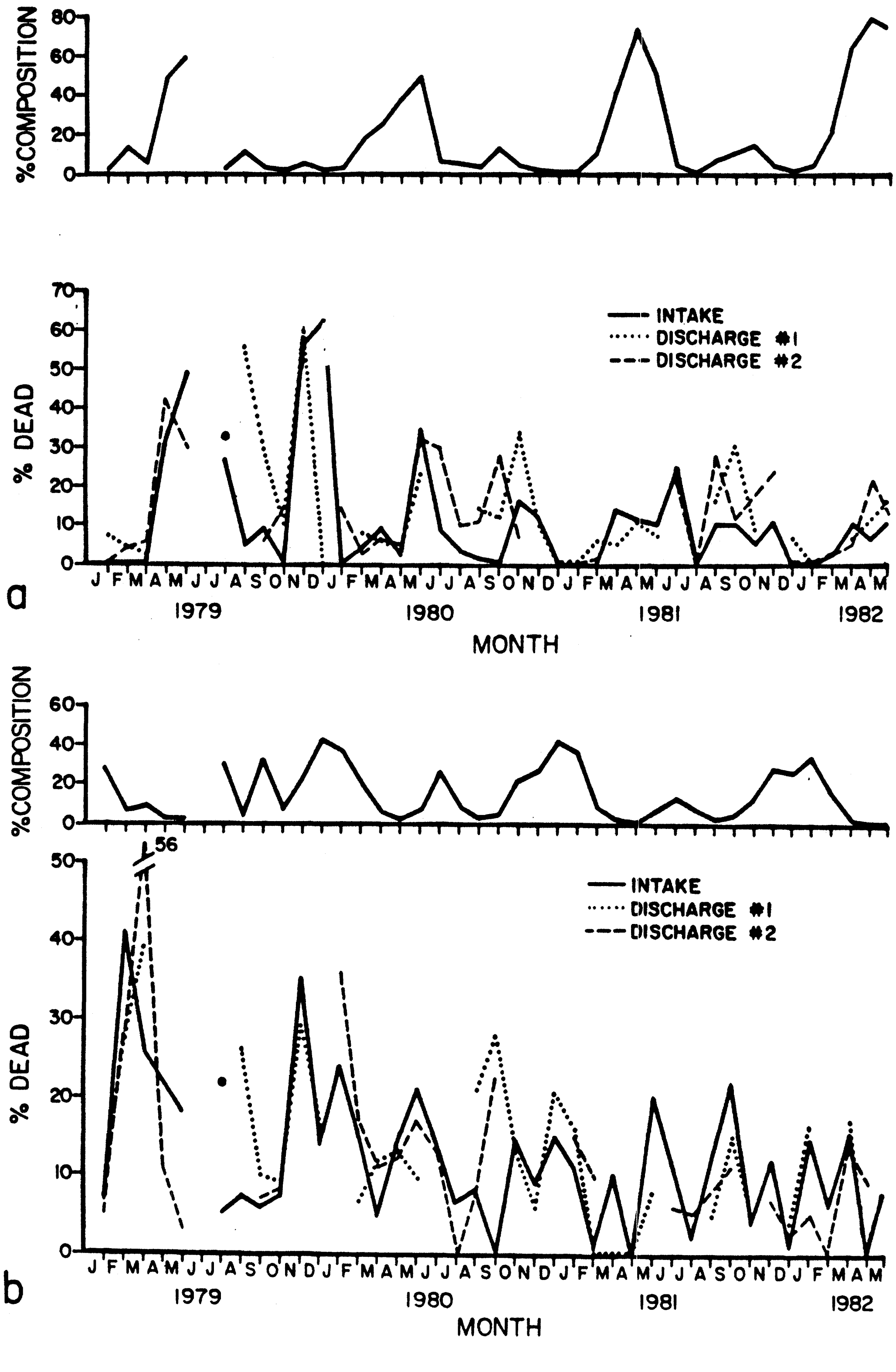


Fig. 41. Monthly mean mortalities (0-hour) for several zooplankton taxa and the mean percent of total zooplankton accounted for by each taxa. a) copepod nauplii, b) Cyclops spp. C1-C5,

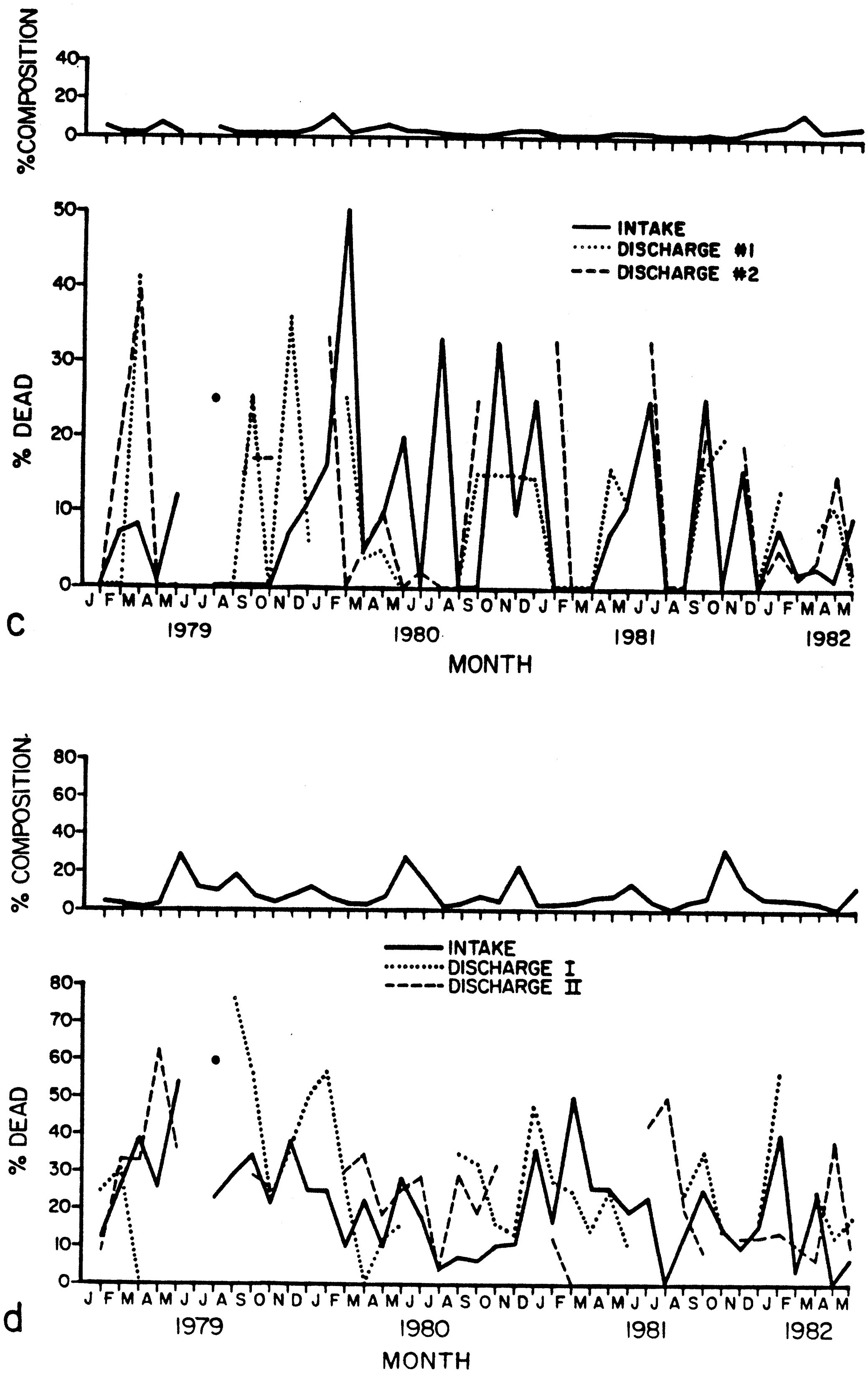


Fig. 41. Continued. c) Cyclops spp. C6, d) Diaptomus spp. C1-C5,

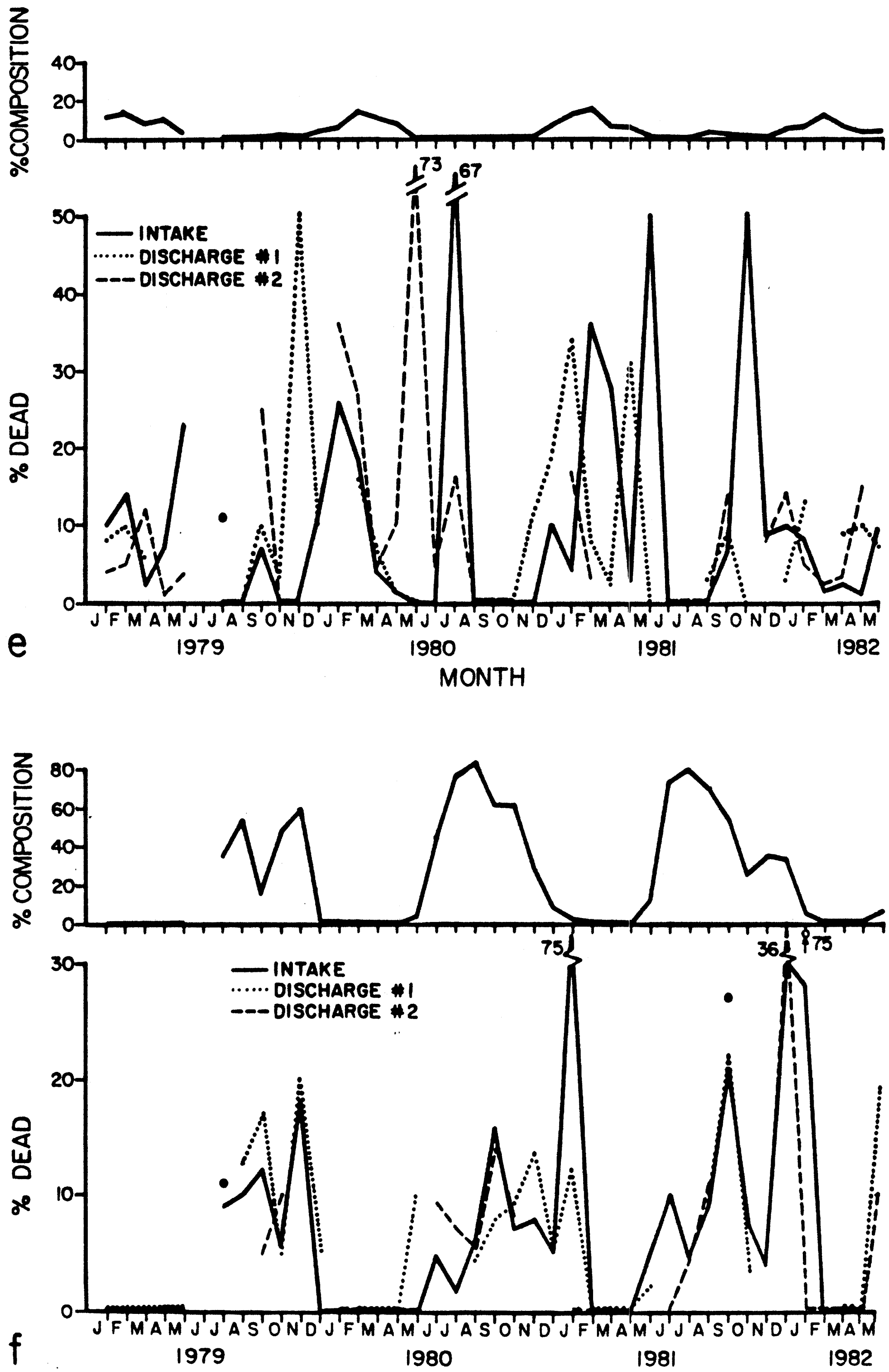


Fig. 41. Continued. e) <u>Diaptomus</u> C6, f) <u>Bosmina longirostris</u>,

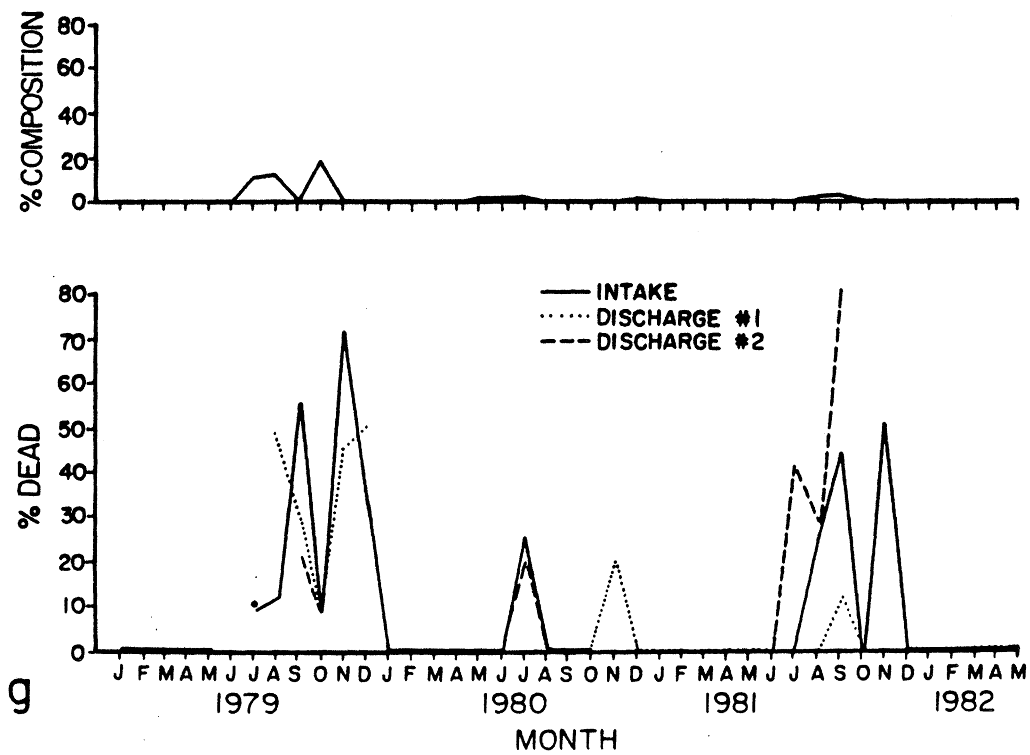


Fig. 41. Concluded. g) Daphnia retrocurva.

Discharge mortalities that were significantly higher than intake mortalities were also detected in April and May, 1982, for Unit 1 and Unit 2 discharge incubations.

Immature *Cyclops* spp.

Immature *Cyclops* spp. were most abundant in June and July, and the fall-winter period beginning in October. Immature *Cyclops* spp. exhibited highest 0-hour mortalities in February and March 1979 (Fig. 41b). The range of 0-hour intake mortalities was 0-36%, with a mean of 11%. Mortalities over the study period ranged from 0 to 56% for Unit 2 discharge, and from 0 to 39% (mean = 14%) for Unit 1 discharge. The only months in which discharge mortalities were not significantly higher than intake mortalities were February and May (Tables 10-12). Significantly higher discharge than intake mortalities occurred in each of three years in January (1980, 1981, 1982) and October (1979, 1980, 1981). Significantly higher discharge than intake mortalities also occurred in July 1979 and 1980. Other discharge mortalities significantly higher than intake values occurred in March (0-hour), August (0 and 6-hour), November (24-hour) and December (0-hour) 1979, April (24-hour) and September (0-hour) 1980, and June (6 and 24-hour) 1981. Many significant differences coincided with the times of highest abundance. High lake water temperatures were not associated with increased discharge mortalities.

Immature *Diaptomus* spp.

Immature *Diaptomus* spp., most abundant in late summer and early fall, generally had higher 0-hour mortalities than did immature *Cyclops* spp. Intake mortalities at 0-hour ranged from 0 to 54%, with a simple mean of 21%. Mortality ranged from 0 to 77% (mean = 28%) in Unit 1 discharge incubations,

and from 0 to 63% (mean = 25%) in Unit 2 discharge incubations. Highest mortalities were observed in April 1979 (Unit 2 discharge), May 1979 (intake), and August 1979 (Unit 1 discharge) (Fig. 41d). Highest mortalities usually were not associated with high water temperatures. Immature *Diaptomus* spp. copepodites had discharge mortalities significantly higher than intake mortalities in at least one incubation x discharge comparison for all months except January and February (Tables 10-12). In 1979, mortality differences during April, July to September, and December were statistically significant. March, and August to November 1980 incubations also yielded significant mortality differences. During 1981, discharge mortalities were higher than intake mortalities in March, June, September, and October. The April and May discharge mortality values were significantly higher than intake rates in 1982. The period of maximum abundance was also the period when most significant mortality differences were observed.

Adult *Cyclops* spp.

Adult *Cyclops* had two population peaks, one in July, and one in late fall-winter. The range of intake and discharge 0-hour mortalities for adult *Cyclops* spp. during 1979-1982 was 0-50 % (Fig. 41c). Adult *Cyclops* spp. had significantly higher discharge than intake mortalities in a total of six incubation x discharge comparisons from three months (Tables 10-12). Units 1 and 2 discharge mortalities were significantly higher than intake mortalities in March 1979. The July 1979 Unit 2 discharge incubation mortality was significantly higher than the intake mortality; no Unit 1 discharge incubations were conducted in July 1979. Only the July population peak coincided with significantly higher discharge than intake mortalities.

Adult Diaptomus spp.

Adult Diaptomus spp. copepodites were most abundant in winter and spring. Highest 0-hour mortalities for adult Diaptomus spp. were: 73% (Discharge 1; May 1980), 67% (intake; July 1980), and 50% (Discharge 2; November 1979) (Fig. 41e). The low range of mortality for all units was 0%. High mortality values were observed when absolute numbers of adult Diaptomus spp. were low, and are based on small samples.

Discharge mortalities of adult Diaptomus were significantly ($p < 0.05$) higher than intake mortalities on many more occasions than those of adult Cyclops spp. With one exception (July 1979; 0-hour), all significant discharge vs. intake mortality differences were observed during the December to April period when adult Diaptomus were a significant percentage of the zooplankton population. At least one incubation x discharge combination comparison of discharge versus intake mortality was significant in each April, 1979-1982 (Tables 10-12). January, February, and March 1979 discharge mortalities were significantly higher than intake mortalities in at least one incubation comparison. The concurrent months of December 1980 and January 1981 each had several discharge mortalities that were significantly higher than intake mortalities.

Bosmina longirostris

Bosmina longirostris population peak was reached in early to mid-summer, when it was a dominant component of the plankton. Bosmina longirostris displayed large fluctuations in both numbers and mortality. Mortality values reached 75% for both intake (January 1981) and Unit 1 discharge (January 1982), ranging from a low of 0%; highest mortality at Unit 2 discharge was 36%

in December 1981 (Fig. 41f). However, Bosmina were rare at this time, and the mortality estimates are of questionable accuracy. Mean mortalities for the intake, Unit 1 discharge and Unit 2 discharge were 12, 11, and 8% respectively. In general, B. longirostris were abundant only from June through December, with highest densities in June, July, and August. It was only in these months that discharge mortalities were significantly greater than intake mortalities (Tables 10-12). These occurred in at least one incubation x discharge x month comparison from May through December of the study.

Daphnia retrocurva

Daphnia spp. were moderately abundant nearshore only during late summer. Mortalities of Daphnia retrocurva ranged from 0 to 71% for the intake, from 0 to 50% for Unit 1 discharge, and from 0 to 80% for Unit 1 discharge (Fig. 41g). Numbers of D. retrocurva were low during most of the study, and all statistics were based on small numbers. Few incubations contained sufficient Daphnia spp. to test for significance of mortality differences. Thus mortalities at each incubation were calculated for total Daphnia spp., of which D. retrocurva was a large proportion. Only two incubations yielded discharge mortalities significantly higher than intake mortalities, December 1979 (0-hour), and August 1979 (0-hour) (Tables 10-12).

Trends in Mortalities over the 1975-1982 Period

Weighted mean mortalities for the 29 most common zooplankton taxa are given for the 1975-1982 period in Tables 13-15 for 0-, 6-, and 24-hour incubations of samples from the intake, and two discharge locations. There were small differences in mortalities, both between discharge locations, and

Table 13. Mean mortalities over the 1975-1982 period in the 0-hour incubation samples calculated as weighed means ($\bar{x}_w$) for 29 zooplankton taxa in intake and discharge samples. n is the number of months represented. Mean percent composition values are presented as weighed means (%comp). Modified from Evans et al. (1986) with permission.

Taxon	Intake		Discharge 1		Discharge 2		
	$\bar{x}_w$	n	$\bar{x}_w$	n	$\bar{x}_w$	n	%comp
Copepod nauplii	14.0	85	13.3	73	17.7	39	13.0
Cyclops spp. C1-C5	9.4	85	10.3	72	13.0	39	17.2
Cyclops bicuspidatus thomasi C6	6.5	81	8.1	66	11.7	38	3.0
Cyclops vernalis C6	5.1	31	3.4	26	3.0	14	0.2
Tropocyclops C1-C5	19.5	25	11.2	25	15.4	9	0.1
Tropocyclops prasinus mexicanus C6	5.5	51	5.6	47	5.0	17	1.6
Diaptomus spp. C1-C5	17.1	85	22.7	73	27.2	39	8.7
Diaptomus ashlandi C6	8.3	75	9.1	56	10.7	31	6.1
Diaptomus minutus C6	5.4	76	11.9	65	9.2	35	1.8
Diaptomus oregonensis C6	6.2	46	7.6	47	9.5	22	2.0
Diaptomus sicilis C6	4.6	49	7.3	44	4.8	25	2.1
Epischura C1-C5	29.6	39	31.8	33	28.0	18	0.5
Epischura lacustris C6	26.2	18	21.2	18	11.5	8	0.1
Eurytemora C1-C5	8.8	47	10.3	39	11.6	22	1.2
Eurytemora affinis C6	16.7	31	10.5	26	14.8	8	0.2
Limnocalanus C1-C5	35.3	23	42.6	24	50.9	13	0.5
Limnocalanus macrurus C6	6.6	32	13.6	27	25.9	19	2.0
Bosmina longirostris	8.7	69	8.5	62	8.9	30	29.0
Ceriodaphnia quadrangula	4.4	8	17.5	9	9.2	6	0.1
Chydorus sphaericus	3.3	32	2.3	28	3.0	17	0.6
Daphnia galeata mendotae	14.2	41	17.2	38	11.2	21	0.5
Daphnia retrocurva	17.4	47	18.4	44	12.6	23	2.4
Diaphanosoma leuchtenbergianum	46.3	18	40.4	20	14.3	4	0.2
Eubosmina coregoni	6.9	50	7.4	49	12.8	23	5.3
Holopedium gibberum	36.9	20	37.8	17	53.3	5	0.1
Leptodora kindtii	26.5	13	41.9	12	40.0	2	0.0
Polyphemus pediculus	30.6	12	13.3	9	30.8	4	0.0
Asplanchna spp.	6.1	46	4.2	44	9.9	21	1.3
Total Zooplankton	10.2	85	11.4	73	13.4	39	

Table 14. Mean mortalities over the 1975-1982 period in the 6-hour incubation samples calculated as weighed means ($\bar{x}_W$) for 29 zooplankton taxa in intake and discharge samples. n is the number of months represented. Mean percent composition values are presented as weighed means (%comp).

Taxon	Intake		Discharge 1		Discharge 2		
	$\bar{x}_W$	n	$\bar{x}_W$	n	$\bar{x}_W$	n	%comp
Copepod nauplii	13.9	83	14.1	71	15.9	39	11.9
Cyclops spp. C1-C5	9.9	84	10.7	72	10.1	39	17.2
Cyclops bicuspidatus thomasi C6	7.9	82	9.0	70	11.3	37	2.9
Cyclops vernalis C6	3.3	31	6.3	25	8.8	10	0.2
Tropocyclops C1-C5	9.4	27	28.0	23	7.7	7	0.1
Tropocyclops prasinus mexicanus C6	6.3	52	8.0	50	11.1	19	1.5
Diaptomus spp. C1-C5	17.5	84	23.3	72	22.3	39	8.6
Diaptomus ashlandi C6	9.3	69	11.6	62	12.6	30	6.2
Diaptomus minutus C6	8.3	75	13.6	67	12.1	31	1.6
Diaptomus oregonensis C6	4.1	48	6.7	44	11.0	21	1.8
Diaptomus sicilis C6	6.6	43	6.9	44	6.2	26	2.3
Epischura C1-C5	17.7	35	26.7	35	21.2	15	0.4
Epischura lacustris C6	42.9	18	36.1	21	8.3	8	0.1
Eurytemora C1-C5	8.4	45	11.2	41	7.8	16	1.2
Eurytemora affinis C6	10.5	29	12.8	28	16.7	13	0.1
Limnocalanus C1-C5	45.2	22	40.2	21	33.2	13	0.6
Limnocalanus macrurus C6	4.7	31	9.1	30	7.5	21	2.1
Bosmina longirostris	8.6	67	9.9	60	7.0	30	29.9
Ceriodaphnia quadrangula	4.3	11	13.2	9	4.7	5	0.1
Chydorus sphaericus	3.4	38	2.5	28	1.8	17	0.6
Daphnia galeata mendotae	15.2	43	18.0	39	13.6	25	0.6
Daphnia retrocurva	20.8	48	25.3	42	13.2	20	2.5
Diaphanosoma leuchtenbergianum	56.7	21	63.7	16	8.3	5	0.2
Eubosmina coregoni	7.5	47	11.2	47	11.2	19	5.5
Holopedium gibberum	37.7	12	44.7	15	42.9	6	0.1
Leptodora kindtii	73.7	13	65.5	14	80.0	3	0.1
Polyphemus pediculus	13.2	11	53.6	9	15.4	6	0.0
Asplanchna spp.	7.2	43	7.8	41	9.8	18	1.2
Total Zooplankton	10.6	84	12.7	72	11.0	39	

Table 15. Mean mortalities over the 1975-1982 period in the 24-hour incubation samples calculated as weighed means ($\bar{x}_w$) for 29 zooplankton taxa in intake and discharge samples. n is the number of months represented. Mean percent composition values are presented as weighed means (%comp).

Taxon	Intake		Discharge 1		Discharge 2		
	$\bar{x}_w$	n	$\bar{x}_w$	n	$\bar{x}_w$	n	%comp
Copepod nauplii	13.4	84	16.8	73	12.8	39	10.8
Cyclops spp. C1-C5	10.6	85	12.6	72	12.3	39	17.1
Cyclops bicuspidatus thomasi C6	9.0	82	11.8	70	12.3	37	3.0
Cyclops vernalis C6	4.2	27	6.9	28	0.0	11	0.2
Tropocyclops C1-C5	15.3	16	17.5	24	13.6	10	0.1
Tropocyclops prasinus mexicanus C6	5.9	52	8.1	49	4.1	18	1.6
Diaptomus spp. C1-C5	15.9	85	22.2	73	20.2	39	8.6
Diaptomus ashlandi C6	12.8	70	17.8	62	18.2	32	6.3
Diaptomus minutus C6	12.1	74	20.8	66	13.4	32	1.8
Diaptomus oregonensis C6	8.0	50	12.1	47	11.1	17	2.1
Diaptomus sicilis C6	8.2	45	9.1	44	9.9	24	2.4
Epischura C1-C5	21.2	37	32.5	31	13.0	17	0.4
Epischura lacustris C6	23.5	21	30.8	19	10.5	10	0.1
Eurytemora C1-C5	11.7	43	18.6	38	9.2	23	1.1
Eurytemora affinis C6	16.5	30	15.8	29	11.4	14	0.2
Limnocalanus C1-C5	44.6	24	48.3	19	43.4	12	0.5
Limnocalanus macrurus C6	6.9	30	6.0	32	8.7	19	2.2
Bosmina longirostris	10.8	72	10.6	62	10.7	32	30.0
Ceriodaphnia quadrangula	15.5	9	23.4	9	11.5	4	1.0
Chydorus sphaericus	4.2	39	3.3	29	3.2	17	0.7
Daphnia galeata mendotae	20.7	46	21.7	39	20.9	25	0.6
Daphnia retrocurva	28.6	52	25.0	43	16.5	22	2.4
Diaphanosoma leuchtenbergianum	47.9	18	62.9	13	85.7	4	0.1
Eubosmina coregoni	10.1	47	15.5	45	13.3	19	5.9
Holopedium gibberum	29.7	12	69.2	10	25.0	5	0.1
Leptodora kindtii	65.7	14	75.0	9	75.0	3	0.0
Polyphemus pediculus	14.3	13	15.4	8	13.3	5	0.0
Asplanchna spp.	8.8	49	12.2	36	11.5	18	1.3
Total Zooplankton	12.0	85	14.5	73	12.8	39	

among incubation times. Total zooplankton weighted mean mortalities ranged, for the three incubation periods, from 10.2 to 12.0% over the 86-month period for intake samples, from 11.4 to 14.5% for unit 1 discharge samples, and from 11.0 to 13.4% for Unit 2 discharge samples (Tables 13-15).

Zooplankton taxa which were relatively abundant (i.e., >5 percent composition) in the samples generally had weighted mean mortalities less than 15% (Tables 13-15). Immature copepodid (C1-C5) stages of *Epischura lacustris*, *Limnocalanus macrurus*, and *Diaptomus* spp. had weighted mean intake and discharge mortalities greater than 20% (Tables 13-15). Four rare cladoceran species, *Diaphanosoma leuchtenbergianum*, *Holopedium gibberum*, *Leptodora kindtii*, and *Polyphemus pediculus* had the highest mortalities, greater than 25% in all cases. *Leptodora kindtii* has a large and fragile body that is particularly subject to mechanical damage.

In general, the relationship between size and mortality differences was weak (Evans et al. 1982). Only the large (>1.5μm) zooplankters appear to be subject to relatively higher mortality in discharge units. These taxa include adult *Limnocalanus macrurus* and *Leptodora kindtii*.

The statistical significance of plant passage mortality for the combined 1975 to 1982 period was assessed for Units 1 and 2 discharges, and for all incubation periods (Tables 16 and 17). With the exception of the Unit 2 discharge, 6-hour incubations, several zooplankton taxa had significantly higher discharge than intake mortalities at each discharge location and incubation time.

Significantly higher discharge than intake mortalities were detected for calanoid copepodites (C1-C6) in all discharge x incubation comparisons for 1975-1982 (Table 17). The overall differences in intake versus discharge

Table 16. Zooplankton taxa for which discharge mortalities were significantly higher than intake mortalities over the 1975-1982 period as determined by the Wilcoxon sign-rank test. Intake and discharge values from a month were used only if both values were based on the observation of at least ten animals. n is the number of monthly pairs of values examined, p is the attained level of significance, and $\bar{d}$ is the mean monthly difference in mortalities, discharge minus intake. Modified from Evans et al. (1986) with permission.

Incubation	Taxon	n	p	$\bar{d}$
	DISCHARGE UNIT 1			
0-hr	*Diaptomus* spp. C1-C5	53	0.00	9.6%
	Diaptomus minutus C6	27	0.02	4.6%
	Eurytemora affinis C1-C5	17	0.04	1.7%
	Limnocalanus macrurus C6	11	<0.01	8.6%
	Daphnia retrocurva	20	0.04	5.2%
6-hr	*Diaptomus* spp. C1-C5	53	0.00	6.3%
	Diaptomus minutus C6	21	0.00	6.5%
	Diaptumus oregonensis C6	14	0.03	3.0%
	Limnocalanus macrurus C6	11	<0.02	3.8%
	Daphnia galeata	12	<0.02	6.8%
	Eubosmina coregoni	19	0.02	4.5%
24-hr	*Diaptomus* spp. C1-C5	50	0.00	6.4%
	Diaptomus ashlandi C6	32	0.05	2.0%
	Diaptomus minutus C6	21	0.05	4.0%
	DISCHARGE UNIT 2			
0-hr	*Diaptomus* spp. C1-C5	23	0.01	9.0%
	Total Zooplankton	26	0.04	2.5%
24-hr	*Diaptomus* spp. C1-C5	19	0.02	5.4%
	Total Zooplankton	26	0.03	2.1%

Table 17. Major zooplankton categories for which discharge mortalities were significantly higher than intake mortalities over the 1975-1982 period as determined by the Wilcoxon sign-rank test. n is the number of monthly pairs of values examined, p is the attained level of significance, and $\bar{d}$ is the mean monthly difference in mortalities, discharge minus intake. Modified from Evans et al. (1986) with permission.

MAJOR ZOOPLANKTON CATEGORY RESULTS

Incubation	Taxon	n	p	$\bar{d}$
	DISCHARGE UNIT 1			
0-hr	Calanoids C1-C6	60	0.00	6.0%
	Calanoids C1-C5	60	0.00	6.0%
	Diaptomus spp. C1-C6	60	0.00	6.7%
	Diaptomus spp. C6	55	0.03	4.0%
	Total zooplankton	60	0.01	1.6%
6-hr	Calanoids C1-C6	59	0.00	5.8%
	Calanoids C1-C5	59	0.00	6.7%
	Diaptomus spp. C1-C6	59	0.00	5.5%
	Diaptomus spp. C6	55	0.02	3.1%
	Total zooplankton	59	0.00	2.1%
24-hr	Cyclopoids C1-C6	60	0.02	1.8%
	Calanoids C1-C6	60	0.00	5.1%
	Calanoids C1-C5	60	0.00	5.9%
	Diaptomus spp. C1-C6	60	0.00	5.2%
	Daphnia spp.	41	0.04	3.4%
	Total zooplankton	60	0.02	1.9%
	DISCHARGE UNIT 2			
0-hr	Calanoids C1-C6	26	0.01	6.0%
	Calanoids C1-C5	26	0.00	8.8%
	Diaptomus spp. C1-C6	26	0.01	6.1%
24-hr	Cyclopoids C1-C6	26	0.02	2.9%
	Calanoids C1-C6	26	0.02	3.8%
	Diaptomus spp. C1-C6	26	0.03	3.9%

mortality ranged from 3.8 to 6.0%. Many of the subgroupings of calanoid copepods also had significantly higher discharge than intake mortalities. Immature calanoid copepodite (C1-C5) mortality from 1975 to 1982 was significant in all incubation x discharge tests (Table 17).

Mortality among the calanoid subgroups, *Diaptomus* spp. (C1-C5) and *Diaptomus* spp. (C1-C6) was also significant in all comparisons. Adult *Diaptomus* spp. had significantly higher mortalities in the Unit 1 discharge than intake for 0- and 6-hour incubations (Table 17). When the *Diaptomus* spp. adults were divided into the component species, significant mortality differences were detected. While mortalities of *D. minutus* were not significantly higher in Unit 2 discharge than intake incubations, they were significantly higher in 0, 6, and 24-hour, Unit 1 discharge incubations (Table 16). Both *D. oregonensis* and *D. ashlandi* were significantly affected by plant passage as determined by the Unit 1 discharge, 6-hour (*D. oregonensis*) and 24-hour (*D. ashlandi*) incubations (Table 16).

Discharge mortalities for two other calanoid copepods, *Limnocalanus macrurus* (C6) and *Eurytemora affinis* (C1-C5) were significantly higher than intake mortalities for the 1975 to 1982 period (Table 16). Adult *L. macrurus* had significantly higher mortalities in intake than discharge waters for the 0- and 6-hour incubations. *Eurytemora affinis* Unit 1 discharge, 0-hour mortality was also significantly higher than intake mortality for the 1975-1982 period.

Only one of the cyclopoid subgroupings (cyclopoid copepods C1-C6) had significantly higher discharge than intake mortality during the study period. Units 1 and 2 discharge, 24-hour mortalities were significantly higher than intake mortalities for that group (Table 17). Discharge mortalities of other

subgroups and individual cyclopoid species were not significantly higher than intake mortalities.

Daphnia spp. had significantly higher discharge than intake mortality for Unit 1 discharge, 24-hour incubations (Table 17). Two component species, D. retrocurva (Unit 1 discharge, 0-hour), and D. galeata mendotae (Unit 1 discharge, 6-hour), also had significant mortality differences (Table 16). The bosminid, Eubosmina coregoni, also had significantly higher mortality in the 0-hour, Unit 1 discharge incubations than in intake incubations (Table 16).

Both Unit 1 discharge and Unit 2 discharge total zooplankton mortalities were significantly higher than intake mortalities at 0-, 6-, and 24-hours. Total zooplankton discharge mortality ranged from 1.56 to 2.49% above intake mortality over the 1975-1982 study period.

DISCUSSION

Our results suggest that plant passage is lethal to a small percentage of zooplankton which pass through the condenser cooling system of the power plant (Evans et al. 1986). The mean 0-hour mortality difference for total zooplankton in Unit 1 and Unit 2 discharges averaged less than 3%. These relatively small mean mortality differences are similar to those observed at other power plants on Lake Michigan (Industrial Bio-Test Laboratories, Inc. 1974a, D. L. Wetzel 1975, Limnetics, Inc. 1975, 1976). Furthermore, there was no evidence that delayed mortality effects were significant, either over a 6- or 24-hour period. Similarly, Davies et al. (1976) did not observe a significant long-term (two weeks) increase in zooplankton mortalities.

There was strong evidence that calanoid copepods were most sensitive to plant passage (Evans et al. 1986). Diaptomus, Eurytemora, and Limnocalanus all had significantly higher discharge water than intake water mortalties. Cladocerans were intermediate in sensitivity to plant passage, with Eubosmina coregoni and Daphnia the most sensitive taxa within this group. In contrast, cyclopoid copepods were relatively resistant to damage inflicted as a result of plant passage. Similar differential sensitivity among zooplankton taxa to plant passage has been observed in other studies (Davies and Jensen 1974, D. L. Wetzel 1975).

Zooplankton mortalities were a result of thermal and/or mechanical stresses. Biocides were not a major source of mortality. The power plant chlorinated cooling waters to control biofouling infrequently until 1978 when treatment was discontinued. Entrained sand provided sufficient scouring action to negate the use of biocides. As chlorination was infrequent, mortality studies did not coincide with biocide application.

There was little evidence that thermal stresses were the major cause of zooplankton mortality (Evans et al. 1986). Examination of two sets of evidence, previous studies on zooplankton thermal tolerances and the relationship between zooplankton mortalities and thermal regime, suggest that the power plant generally operated within the thermal tolerance ranges of Lake Michigan zooplankton. Mortalities did not increase in summer when discharge water temperatures were highest and zooplankton most likely to experience thermal regimes at (or above) their upper critical thermal limit. Nor did zooplankton mortalities increase in winter when cold-adapted species were prevalent.

Our previous studies have shown that mortalities in discharge waters were not significantly correlated with ΔT (Evans et al. 1982). Since ΔT showed little seasonal variation, this was not unexpected. Nor were differences between discharge and intake mortalities significantly correlated with discharge water temperature (Evans et al. 1982). We conclude that the moderate thermal elevations (ΔT <12C°) and short-term (minutes) exposures to discharge water temperatures below 35°C were not the major source of stress to zooplankton which pass through the condenser cooling system of the power plant.

Results of other field and laboratory studies support this conclusion. Short-term exposures to moderate thermal elevations do not become stressful to most zooplankton until a critical upper temperature is reached. For many organisms, this temperature is in the 30's °C (Drost-Hansen 1969) although latitudinal variations in tolerance occur (Brown 1929). Moreover, thermal tolerance varies with acclimation temperature (Coker 1934, Heinle 1969). *Diaptomus* spp. copepodites reared at 1°C have a median lethal temperature of 32.6°C (2-minute exposure, ΔT of 31.6 C°) whereas animals reared at 20°C have a median lethal temperature of 34.5°C (2-minute exposure, ΔT of 14.5 C°) (Industrial Bio-Test Laboratories, Inc. 1974b). Furthermore, *Cyclops* spp. copepodites are more tolerant of elevated temperatures than *Diaptomus* spp. copepodites.

One important aspect of thermal tolerance is the sharp decrease in survivorship which may occur as water temperatures are increased by as little as a 1-2 C°. Brown and Crozier (1927-1928) observed that *Daphnia pulex* will live and reproduce near 30°C but will die at 32°C, thus a sharp transition in survivorship occurred near 31°C. Therefore, a power plant may inflict minimal

mortalities on zooplankton by operating at discharge water temperatures 2 or 3 C° below the upper critical temperature. However, a slight increase in temperature may result in a dramatic increase in zooplankton mortalities. Such an increase apparently was observed at the power plant in September 1978 (Evans et al. 1982) when discharge water temperatures slightly exceeded 35°C and 0-hour net mortalities were 14% for Unit 2 (discharge water temperature 35.2°C) and 22% for Unit 1 (discharge water temperature 35.6°C). Other studies have shown that when discharge water temperatures reach 40°C, mortalities may exceed 80% (Reeve 1970, Brauer et al. 1974).

Mechanical stresses probably were the major source of zooplankton mortality at the power plant. Some zooplankton clearly were physically damaged by the plant. Antennae and urosomes were torn, carapaces bent backwards, and the body wall ruptured. However, much of the damage may have occurred during pump sampling. Many of the dead zooplankton collected in intake samples were physically damaged. Studies conducted at the Nanticoke Generating Station showed clear quantitative evidence that zooplankton were physically damaged by plant passage, although mortalities were not determined (Standke and Monroe 1981). Other studies have implicated mechanical stresses as the significant source of mortality both to zooplankton (Carpenter et al. 1974) and fish (Marcy 1973) at power plants where organisms are exposed to moderate thermal elevations for short periods of time.

Factors causing mechanical stress are poorly understood. While some researchers have suggested that mortalities are a linear function of zooplankton size (Wetzel 1975), the relationship probably is best) described by a second- or third-order function. We observed that, for small (<1.5 mm) zooplankton, mortalities were not size related (Evans et al. 1982; this

section). For such taxa, mortalities appear to be a function of inherent taxonomic sensitivies, i.e., calanoids were relatively more sensitive to plant passage than cyclopoid copepods. However, as zooplankton size increases (>1.5 mm), the mortality-size relationship may become stronger.

Power plants are highly variable in their mode of operation (ΔT, discharge water temperature, pumping rate, flow through rate, use of biocides, etc). Comparative studies conducted by the same researchers using the same methods have shown that plant operating characteristics have a significant effect on zooplankton mortalities; rates generally are highest for plants with the greatest ΔT and where discharge water temperatures reach the mid-30's °C (Davies and Jensen 1974, Icanberry and Adams 1974). At the Donald C. Cook Nuclear Plant, where the ΔT (<12 C°) is moderate and discharge water temperatures generally do not exceed 35°C, zooplankton mortalities as a result of plant passage appear to be low (<3%).

SECTION 4

NUMBERS AND BIOMASS OF ZOOPLANKTON PASSING THROUGH THE POWER PLANT

INTRODUCTION

The entrainment program, in addition to estimating the percent of zooplankton killed by plant passage, determines the concentration of zooplankton passing through the plant. This information has several applications. First, by knowing the rate at which the plant withdraws water and associated zooplankton from the lake, estimates can be made of the numbers of zooplankton passing through the plant. Similarly, by estimating zooplankton mortality immediately resulting from plant passage, estimates can be made of the number of zooplankton killed by plant passage. Calculations also can be expressed in terms of biomass.

Comparisons of zooplankton population characteristics in the cooling waters with population characteristics in the nearshore region provide an indication of the region of the water colum from which the intakes draw their water. For example, are zooplankton populations in the cooling waters strongly dominated by epibenthic and benthic forms? If so, this would suggest that the plant withdraws a significant proportion of its water from the deeper regions of the water column.

The entrainment program provides an opportunity to obtain detailed information on zooplankton population dynamics in the nearshore region without the high costs of ship operation. During the cruise season (April to November), these data can be used to examine the short-term (week to week) variability in zooplankton abundances. Furthermore, the entrainment program

provides information on zooplankton community structure over winter and early spring, periods not readily studied from research vessels.

This section addresses the following:

(1) How does the concentration (abundance and biomass) of living and plant-killed zooplankton in the cooling waters vary seasonally and annually?

(2) How representative is the intake as a sampling location for zooplankton abundance estimates in the inshore region?

(3) Is short-term (week to week) variability in zooplankton abundance estimates similar to longer-term (month to month) variability?

MATERIALS AND METHODS

Entrainment Abundance Estimates

Zooplankton were collected once a month from the intake (MTR 1-5) and discharge (Units 1 and 2) forebays. Two 5-minute replicate samples were taken at each station at four sampling times: noon, sunset, midnight, and sunrise. Sampling at the four times helped to account for patchiness and diel differences in the vertical distribution of zooplankton. Samples were simultaneously collected from the intake and discharges. Hale diaphragm pumps were used to draw water from the forebay and pass it through a 30-cm 156 μm mesh net (Fig. 42). Each net was suspended in a barrel of water to help minimize damage to the animals. The volume of water filtered was measured with a flowmeter located in the outflow pipe. Twenty four samples (3 locations x 4 times x 2 replicates) were collected each month when both units were operational. When only one unit was operating, the intake forebay and the discharge forebay of the operational unit were sampled (16 samples total).

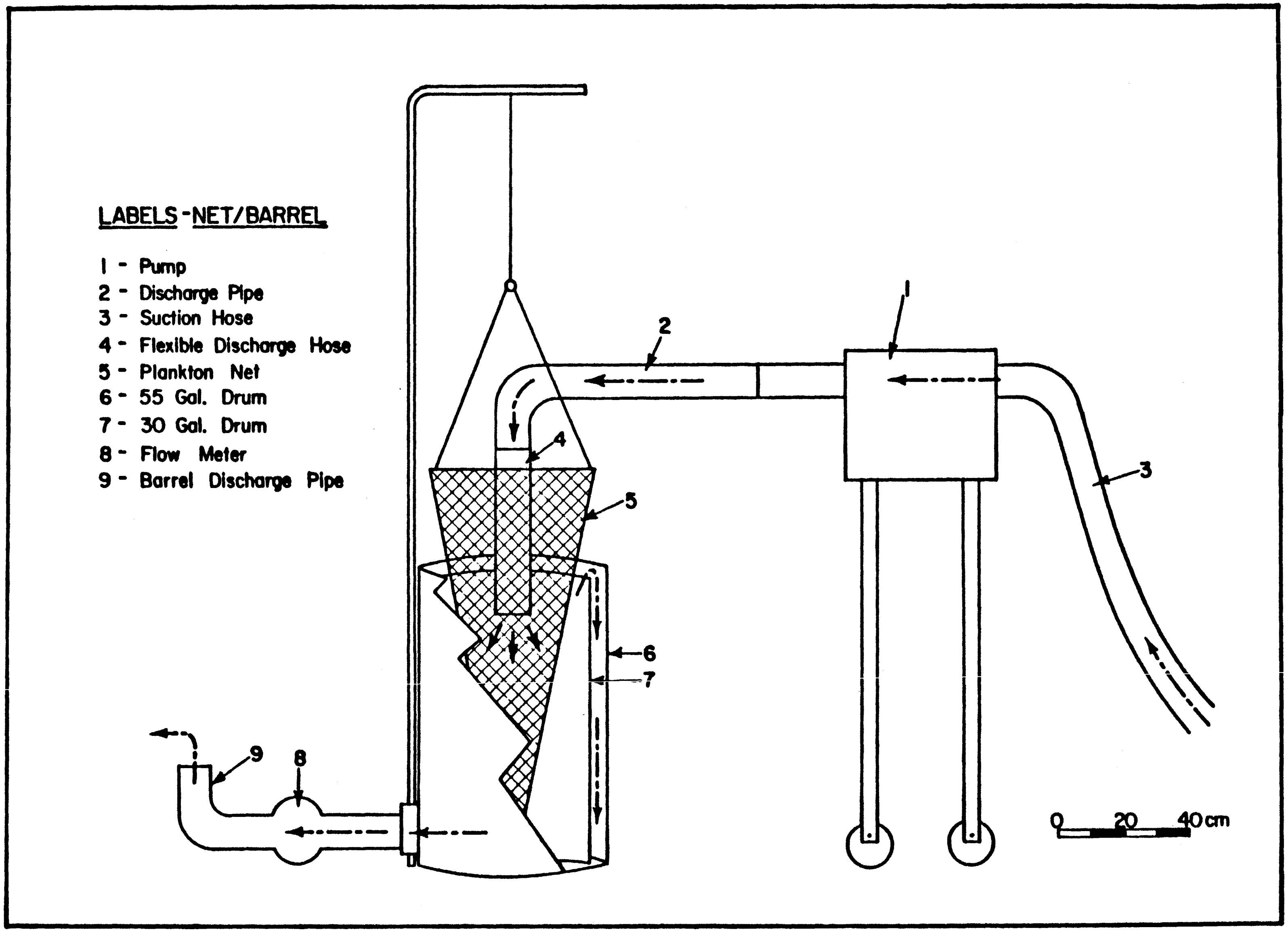


Fig. 42. Pump and net arrangement for zooplankton entrainment abundance samples.

Additional samples were collected at noon and midnight at weekly or biweekly intervals to provide more detailed information on zooplankton population dynamics. All samples were examined by the methods described in Section 1.

Comparison of Concentrations of Major Zooplankton Taxa in the Cooling Waters and Inshore Region

Data collected between 1975 and 1981 were examined to determine whether intake sampling provided abundance estimates which were similar to those obtained by directly sampling the inshore region. The correlation (linear coefficient of correlation) between the 54 concurrent intake and inshore region observations was calculated. Various combinations of data were analyzed as described below. Analysis of variance (one-way, fixed effects) was used to determine whether intake abundance estimates differed significantly (α=0.05) from inshore region abundance estimates for the same 54 observation data sets. The ratio (Rg) of the geometric mean (n=54) of zooplankton densities in the inshore region to the geometric mean of densities in the intake samples was calculated. The geometric mean is a useful way of evaluating central tendency for ratio data (Steel and Torrie 1960). A two-way fixed effects analysis of variance (month x time of day) was performed to determine if the numerically dominant taxa exhibited significant diel (sunset, midnight, sunrise, noon) differences in abundances in intake waters.
An unbalanced study design was used because each of the 12 months of the year were not sampled uniformly over the seven years of the study. In addition, the same analyses as described above were conducted for the epibenthic and benthic microcrustaceans. These taxa, while rare, were commonly observed in the intake waters (Evans et al. 1982). The results of this study also are reported in Evans and Flath (1984).

Four combinations of data were analyzed: (1) mean intake abundance (n=4 diel observations) with the mean abundance of zooplankton in the inshore region (n=7 or 13 stations; Fig. 1), (2) mean intake abundance (n=4 diel observations) with mean abundance in zone 2 (n=5 or 7 stations) in the immediate vicinity of the plant, (3) noon intake abundance (n=1) with the mean abundance in the inshore region (n=7 or 13 stations), and (4) noon intake abundance (n=1) with the mean abundance in zone 2 (n=5 or 7 stations).

The untransformed data did not meet the assumptions of normality. Log-transformed data did meet these assumptions: therefore, statistical analyses were performed on log-transformed data.

RESULTS

Biomass and Numbers of Zooplankton Passing Through the Power Plant and the Estimated Maximum Losses

Billions of zooplankton pass through the plant each month (Fig 43). The number entrained ranged from 250 x 10^9 in March 1982 to 20,709 x 10^9 in July 1979 and averaged 5,081 x 10^9 (Fig. 43). The number of zooplankton entrained was related to zooplankton concentrations and plant pumping rates. More zooplankton passed through the plant during the summer and autumn months when zooplankton concentrations in the lake region nearest the intakes were highest (Fig. 30, Section 2). Average zooplankton concentration in the cooling waters was 23,915/m^3 and ranged from 1,614/m^3 in March 1982 to 96,730/m^3 in July 1979 (Fig. 44). The total number of zooplankton entrained was similar for the years 1979 to 1981 and comparable to those years for the first 5 months of 1982.

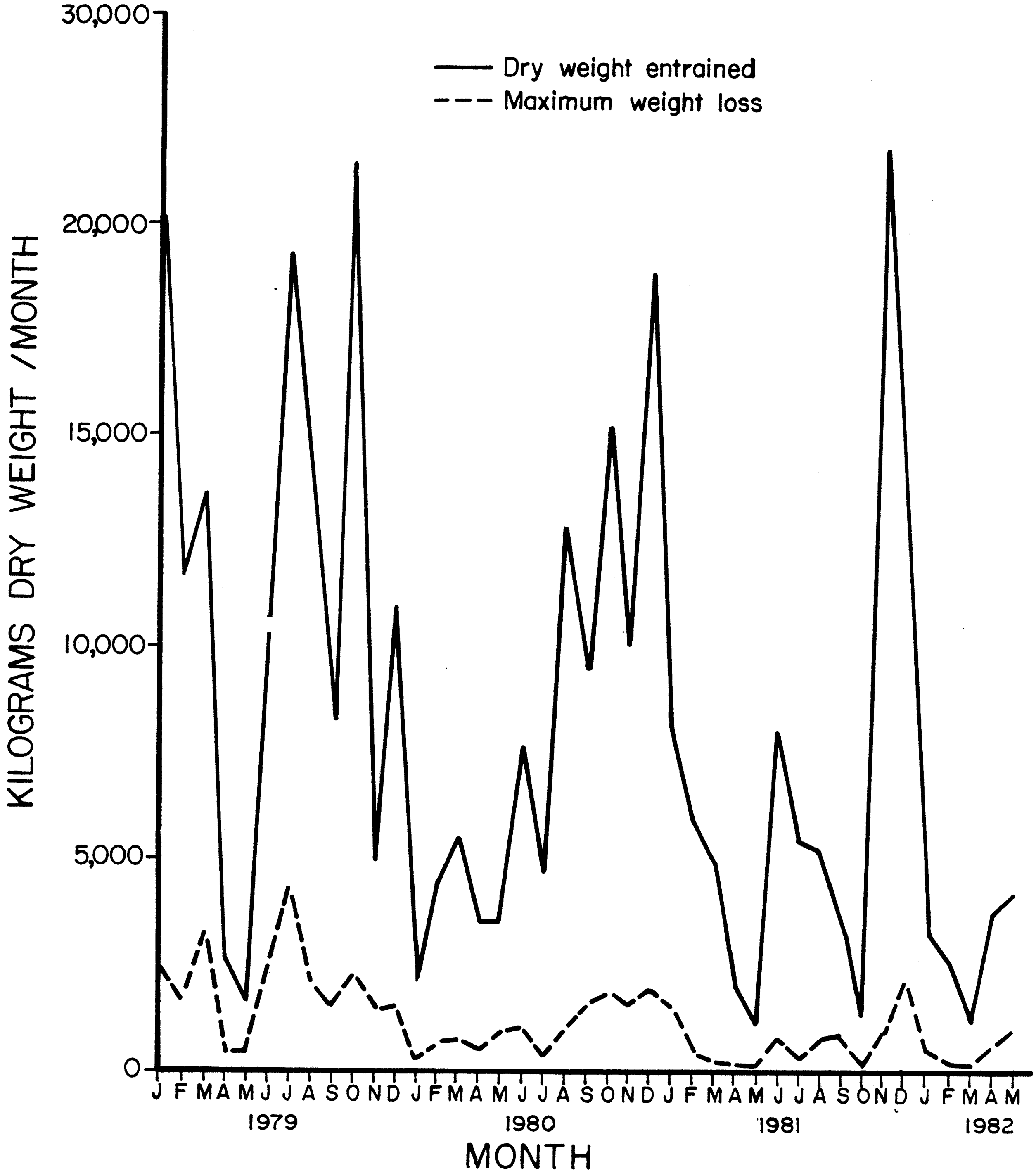


Fig. 43. Monthly estimates of the dry wt of zooplankton entrained and the maximum weight lost from January 1979 to May 1982. There are no data for June 1979.

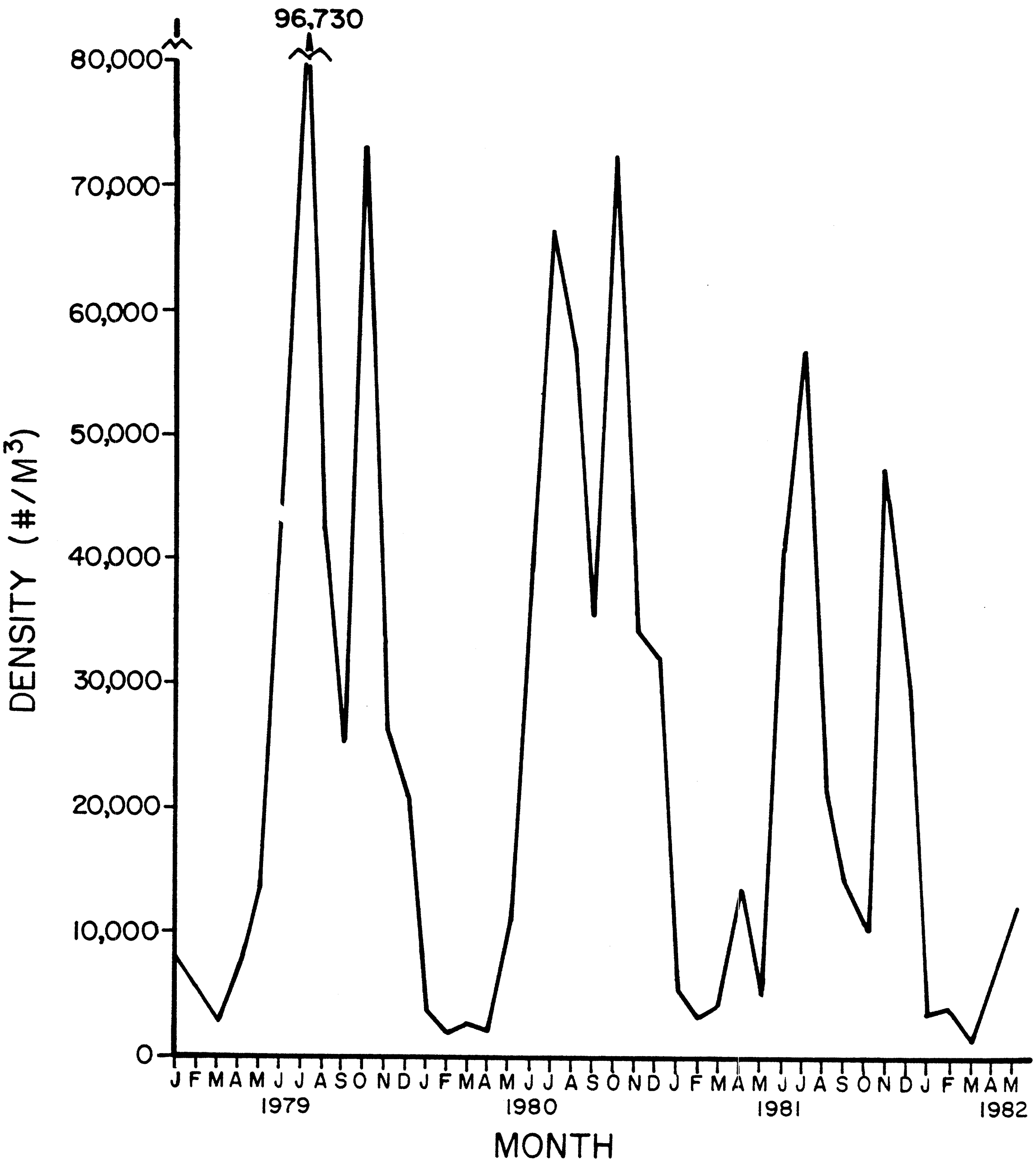


Fig. 44. Total zooplankton densities ($\#/m^3$) in monthly entrainment samples taken from the intake forebay. There are no data for June 1979.

Maximum estimated numerical losses generally followed the numbers entrained curve. Highest numerical loss estimates were calculated for the summer and autumn months when zooplankton populations were largest. The estimates of maximum losses assumed that immediate (0-hour) discharge mortality represented maximum losses of zooplankton in the vicinity of the discharge jets. The actual loss was probably lower (Section 2). This conservative approach was used because the study did not estimate additional mortalities that may have resulted from the discharge of zooplankton into the lake at high velocities.

The monthly biomass of zooplankton entrained (Fig. 45) ranged from a low of 1,117 kg dry wt/month in March 1982 to a high of 21,991 kg dry wt/month in November 1981 and averaged 8,191 kg dry wt/month. Maximum biomass loss estimates averaged 1,135 kg dry wt/month and ranged from 70 kg dry wt/month in October 1981 to 4,482 kg dry wt/month in July 1979. The seasonal pattern of biomass of zooplankton entrained did not match that of the numbers of zooplankton passing through the plant. Highest values of biomass entrained occurred in colder months. This was because winter zooplankton, while less abundant, were dominated by relatively large animals (mean dry wt 3 to 7 μg) while the more numerous summer zooplankton were dominated by relatively small animals (mean dry wt 1 to 2 μg).

Comparison of Zooplankton Abundance in the Cooling Waters and the Inshore Region

Zooplankton abundances in the inshore region (zones 1 to 3) (Fig. 46) exhibited strong seasonal variation from cruise to cruise. Zooplankton standing stocks (Fig. 46) were low in spring and attained maxima in summer and autumn. There was a large decrease in standing stocks between the last cruise

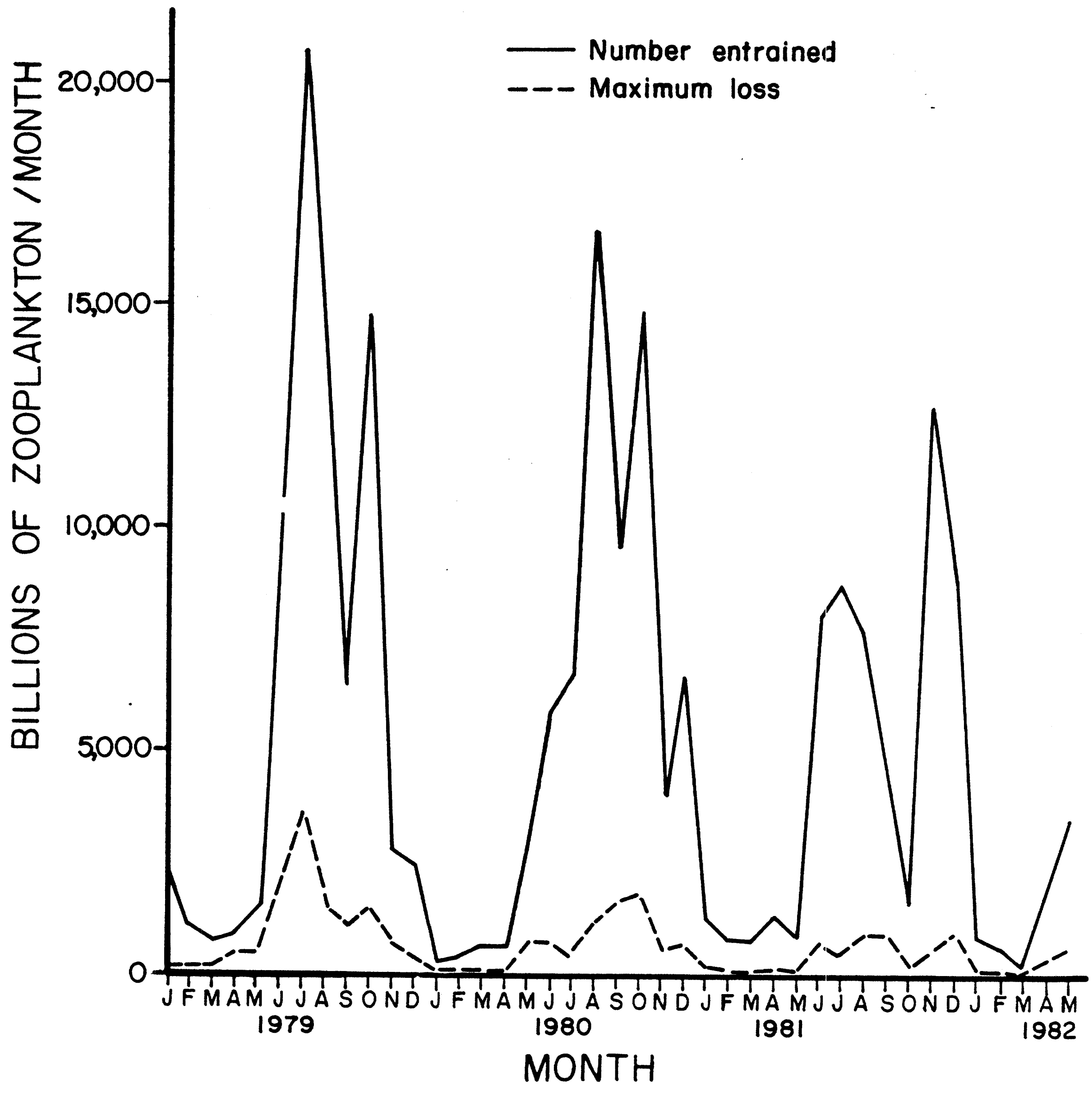


Fig. 45. Estimates of numbers of entrained zooplankton and maximum losses from January 1979 to May 1982. There are no data for June 1979.

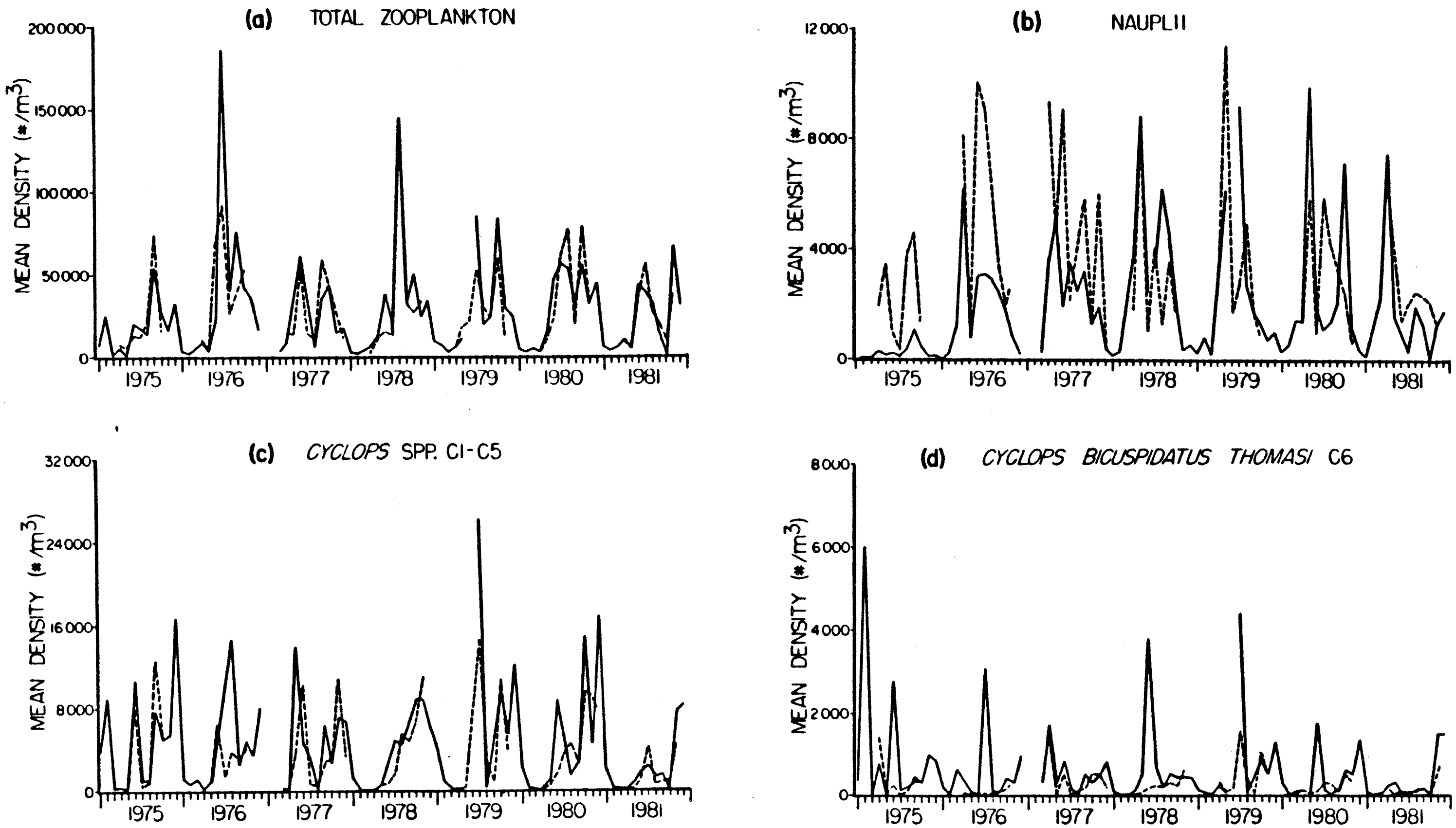


Fig. 46. Comparisons of zooplankton densities in the entrainment abundance samples (dotted line) and in the inshore zone (solid line). Entrainment data points represent the mean of up to four sampling times (sunset, midnight, sunrise, and noon) and inshore zone points represent the mean of up to 13 stations in the 5-10 m depth zone. a) total zooplankton, b) copepod nauplii, c) _Cyclops_ spp. C1-C5, d) _Cyclops_ spp. C6,

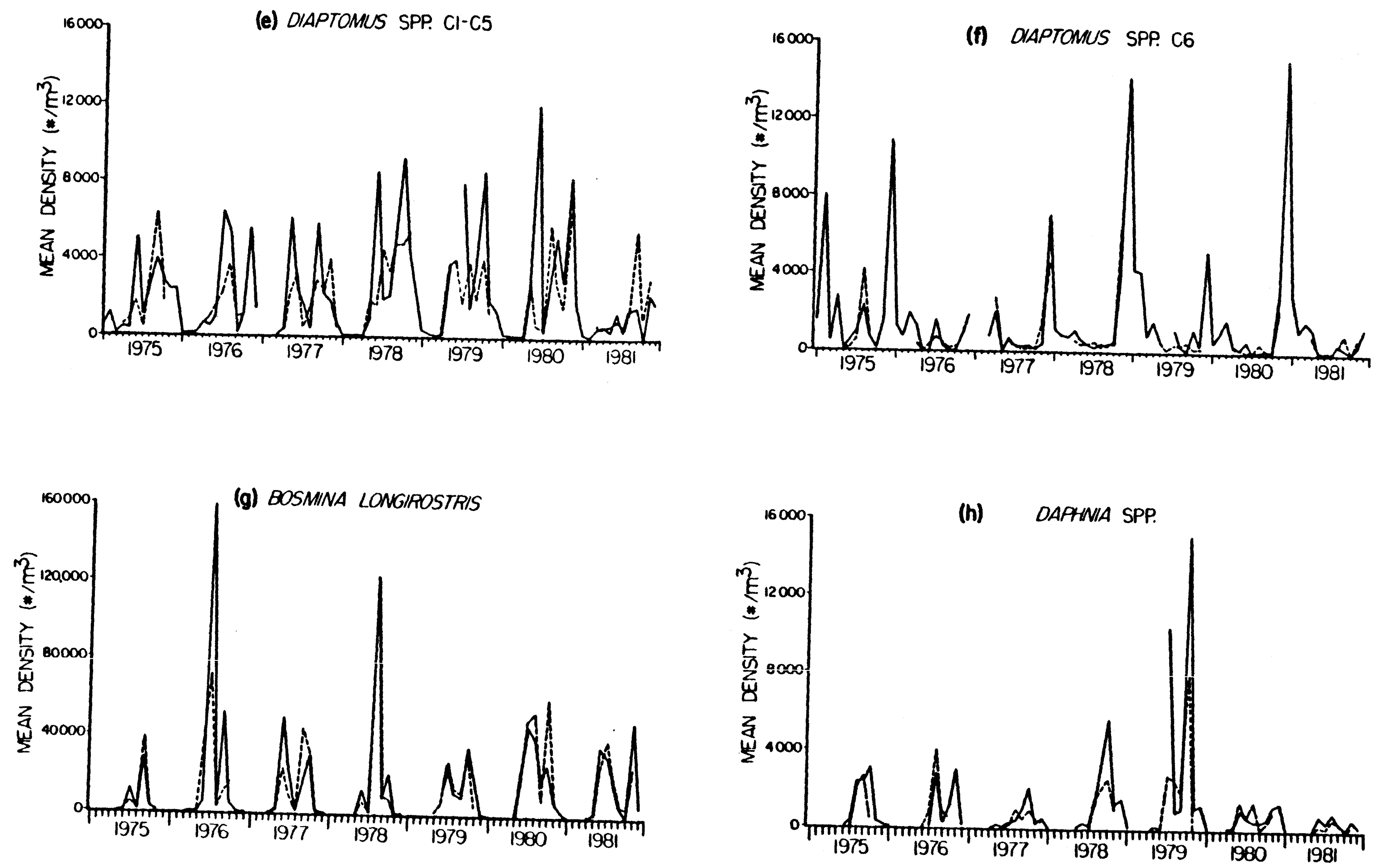


Fig. 46. Continued. e) <u>Diaptomus</u> spp. C1-C5, f) <u>Diaptomus</u> spp. C6, g) <u>Bosmina longirostris</u>, h) <u>Daphnia</u> spp.,

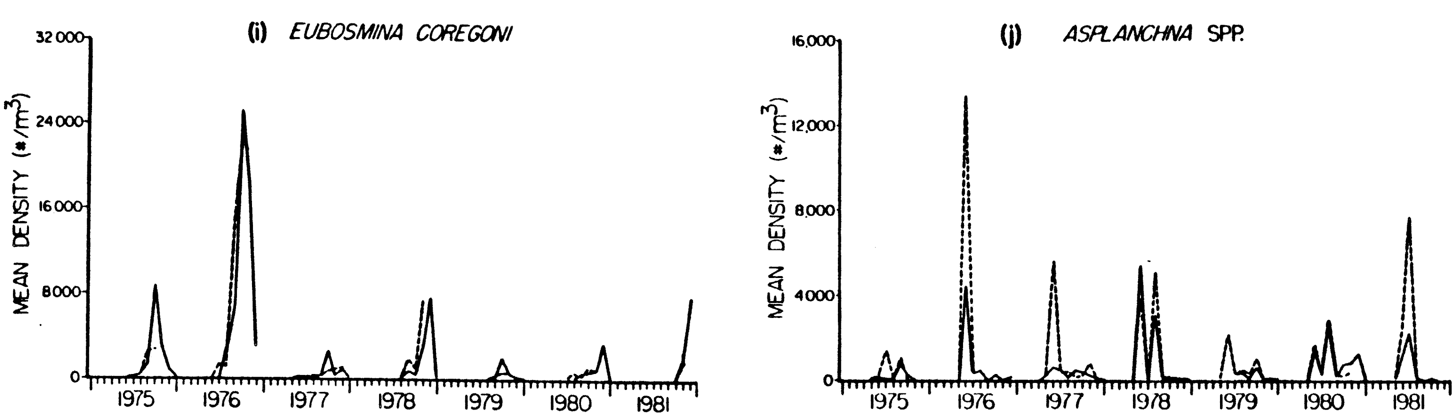


Fig. 46. Concluded. i) Eubosmina coregoni, j) Asplanchna spp. Modified from Evans and Flath (1984), with permission.

of a year and the April cruise of the following year. Zooplankton collected by noon intake sampling (Fig. 46) exhibited similar abundance patterns (seasonal, annual) as zooplankton collected in the inshore region.

Numerically dominant copepod taxa which were common year around were nauplii, immature Cyclops spp. and immature Diaptomus spp., followed by adult Cyclops spp. (primarily C. bicuspidatus thomasi) and adult Diaptomus spp. (D. ashlandi, D. minutus, D. oregonensis, and D. sicilis) (Fig. 46b-f). Cladocerans were abundant only during summer and autumn (Fig. 46g-i). Bosmina longirostris, Eubosmina coregoni, and Daphnia spp. (primarily D. retrocurva and D. galeata mendoate) were the numerical dominants. The rotifer Asplanchna spp. was common only during the summer (Fig. 46j).

Some consistent differences were noted in taxa abundances between the intake and inshore region. Copepod nauplii tended to occur in lower concentrations in intake samples between 1975 and July 1977 when a smaller 20-cm diameter net was used than the 30-cm diameter net used during the remainder of the study. Adult Cyclops bicuspidatus thomasi generally occurred in higher concentrations in the intake series than in inshore region collections, especially during the May to July period.

Noon intake abundances generally were highly correlated ($r>+0.65$) with zooplankton abundances in zone 2, the area in the immediate vicinity of the power plant (Table 18). Lower correlations were observed for copepod nauplii, adult Cyclops spp., and adult C. bicuspidatus thomasi. All correlations were statistically significant ($p<0.05$). Noon intake abundances also were highly correlated with zooplankton abundances in zones 1 to 3, i.e., the region extending 11 km north and south of the plant site. Intake abundances (mean of four diel observations) were highly correlated with abundances in zone 2 and

Table 18. Correlations of field and intake densities for the years 1975 to 1981 (N=55), the geometric mean of the ratio of inshore:intake densities, and the statistical significance (p <.05) of differences in inshore-intake densities.

Taxon	Noon intake vs zones 1-3				Noon intake vs zone 2				All intake vs zones 1-3				All intake vs zone 2			
	r	Ratio	Sig[1]	Sig[2]	r	Ratio	Sig[1]	Sig[2]	r	Ratio	Sig[1]	Sig[2]	r	Ratio	Sig[1]	Sig[2]
Euplankton																
Nauplii	+0.61	1.06	*	ns	+0.58	1.06	*	ns	+0.64	1.04	ns	ns	+0.61	1.04	*	ns
Cyclops spp. C1-C5	+0.87	0.97	ns	ns	+0.86	0.98	ns	ns	+0.85	0.96	ns	ns	+0.84	0.97	ns	ns
Cyclops spp. C6	+0.46	0.91	ns	*	+0.45	0.91	ns	*	+0.38	0.86	*	*	+0.41	0.86	*	*
Cyclops bicuspidatus thomasi C6	+0.48	0.91	ns	*	+0.48	0.91	ns	*	+0.42	0.85	*	*	+0.43	0.86	*	*
Tropocyclops prasinus mexi.[3] C1-C6	+0.89	1.09	ns	ns	+0.89	1.07	ns	ns	+0.93	0.96	ns	ns	+0.92	0.95	ns	ns
Diaptomus spp. C1-C5	+0.78	0.99	ns	ns	+0.78	1.10	ns	ns	+0.78	0.99	ns	ns	+0.78	1.00	ns	ns
Diaptomus spp. C6	+0.77	1.06	ns	ns	+0.79	1.06	ns	ns	+0.85	1.01	ns	ns	+0.86	1.01	ns	ns
D. ashlandi C6	+0.70	1.13	ns	ns	+0.72	1.13	ns	ns	+0.73	1.01	ns	ns	+0.75	1.00	ns	ns
D. minutus C6	+0.66	1.13	ns	ns	+0.67	1.12	ns	ns	+0.71	1.05	ns	ns	+0.71	1.03	ns	ns
D. oregonensis C6	+0.73	1.10	ns	ns	+0.72	1.12	ns	ns	+0.77	0.94	ns	ns	+0.76	0.95	ns	ns
D. sicilis C6	+0.86	1.04	ns	ns	+0.85	1.07	ns	ns	+0.88	0.94	ns	ns	+0.88	0.97	ns	ns
Epischura lacustris C1-C6	+0.83	1.01	ns	ns	+0.82	1.01	ns	ns	+0.90	0.97	ns	ns	+0.89	0.97	ns	ns
Eurytemora affinis C1-C6	+0.89	1.03	ns	ns	+0.89	1.00	ns	ns	+0.95	0.92	ns	ns	+0.94	0.90	ns	ns
Limnocalanus macrurus C1-C6	+0.90	1.02	ns	ns	+0.90	1.02	ns	ns	+0.94	0.79	ns	ns	+0.94	0.79	ns	*
Bosmina longirostris	+0.96	1.01	ns	ns	+0.96	1.00	ns	ns	+0.97	1.00	ns	ns	+0.96	0.99	ns	ns
Daphnia spp.	+0.90	0.75	ns	ns	+0.89	0.95	ns	ns	+0.89	0.92	ns	ns	+0.87	0.92	ns	ns
D. galeata mendotae	+0.73	1.05	ns	ns	+0.73	1.03	ns	ns	+0.76	0.94	ns	ns	+0.75	0.92	ns	ns
D. retrocurva	+0.89	0.93	ns	ns	+0.88	0.94	ns	ns	+0.88	0.90	ns	ns	+0.87	0.92	ns	ns
Eubosmina coregoni	+0.89	1.17	ns	ns	+0.88	1.16	ns	ns	+0.93	1.05	ns	ns	+0.93	1.04	ns	ns
Asplanchna spp.	+0.92	1.13	ns	ns	+0.92	1.12	ns	ns	+0.94	1.07	ns	ns	+0.94	1.06	ns	ns
Epibenthos/Benthos																
Cyclops vernalis C6	+0.43	0.57	*	ns	+0.44	0.50	*	*	+0.48	0.39	*	*	+0.47	0.34	*	*
Alona spp.	+0.25	0.57	*	ns	+0.18	0.54	*	ns	+0.41	0.34	*	*	+0.33	0.33	*	*
Chydorus sphaericus	+0.49	0.68	*	ns	+0.50	0.68	*	*	+0.50	0.56	*	*	+0.49	0.56	*	*
Eurycercus lamellatus	+0.38	0.30	*	ns	+0.36	0.27	*	*	+0.48	0.16	*	*	+0.45	0.14	*	*
Macrothrix laticornis	+0.43	1.02	ns	ns	+0.37	0.98	ns	ns	+0.31	0.50	ns	ns	+0.28	0.48	ns	*
Total	+0.86	1.00	ns	ns	+0.83	1.00	ns	ns	+0.85	0.99	ns	ns	+0.83	0.99	ns	ns

1 Based on ANOVA.
2 Based on median test.
3 *T. prasinus mexicanus*.

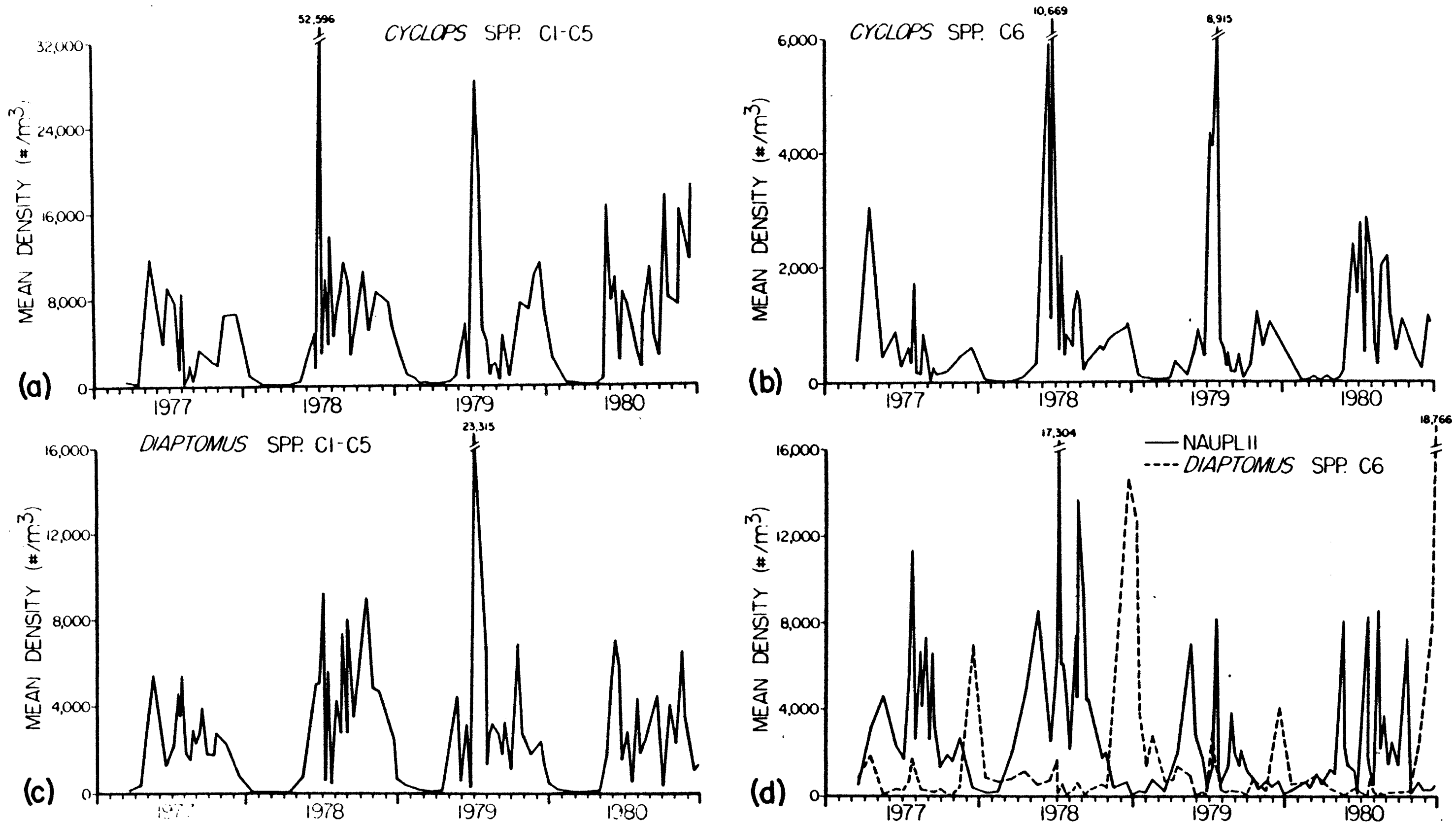
For $\alpha = .05$, $r = .27$; for $\alpha = .01$, $r = .34$ for 54 degrees of freedom.

zones 1 to 3 (Table 18). Overall, there were no large differences in the correlation coefficients for the various combinations of data analyzed.

For most taxa, the ratio (Rg) of the geometric mean of zooplankton abundances in the inshore region to the geometric mean of abundances in the intake approximated 1. Similarly, differences in abundances in the inshore region and in the cooling water were not statistically significant ($p<0.05$) for most taxa. Consistent exceptions were copepod nauplii, adult *Cyclops* spp., and *C. bicuspidatus thomasi* adults. Diel variations in abundance were not statistically significant (month x time of day; one-way analysis of variance) for most taxa with the exception of *Eurytemora affinis* copepodites. Immature *E. affinis* mean abundances at sunset, midnight, sunrise, and noon were 760/m^3, 1,572/m^3, 1,355/m^3, and 872/m^3 respectively while adult abundances were 76/m^3, 541/m^3, 135/m^3, and 35/m^3 respectively.

Supplemental intake sampling (at two-week or weekly intervals) (Fig. 47) showed significant variations in taxa abundance from one week to the next. There was little evidence that populations followed a consistent trend of increase or decrease over monthly intervals.

Rare taxa observed in the intake waters included epibenthic and benthic cladocerans and copepods (Fig. 48), *Chydorus sphaericus*, *Eurycercus* sp., *Alona* spp., *Macrothrix laticornis* , and adult *Cyclops vernalis*, which accounted for less than 0.5% of the microcrustacean standing stocks. Correlations between intake and inshore region sampling for each of these taxa, while statistically significant ($p<0.05$), were low ($r<0.50$: Table 18). Abundances were higher in the intake ($Rg<1.00$) than in the inshore region (Table 18). Diel differences in abundance were statistically significant only for *C. vernalis* copepods and *Eurycercus* sp. Mean sunset, midnight, sunrise, and noon abundances were 7/m^3,



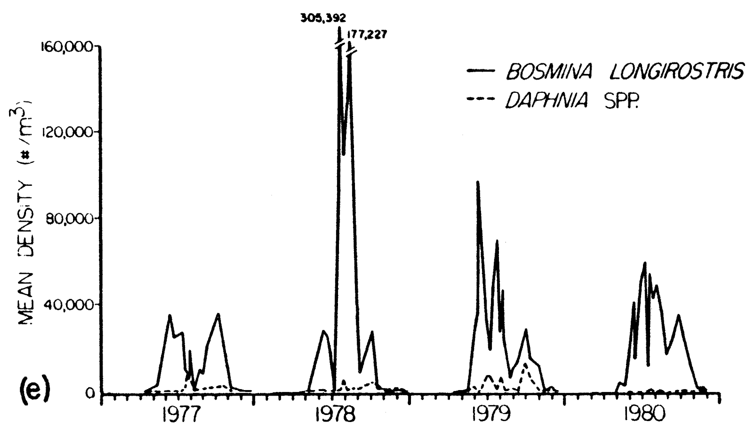


Fig. 47. Variation in abundance of selected zooplankton taxa collected in entrainment abundance samples. Samples were collected at noon and midnight at weekly or bimonthly intervals. a) Cyclops spp. C1-C5, b) Cyclops spp. C6, c) Diaptomus spp. C1-C5, d) Diaptomus spp. C6 and copepod nauplii, e) Bosmina longirostris and Daphnia spp.

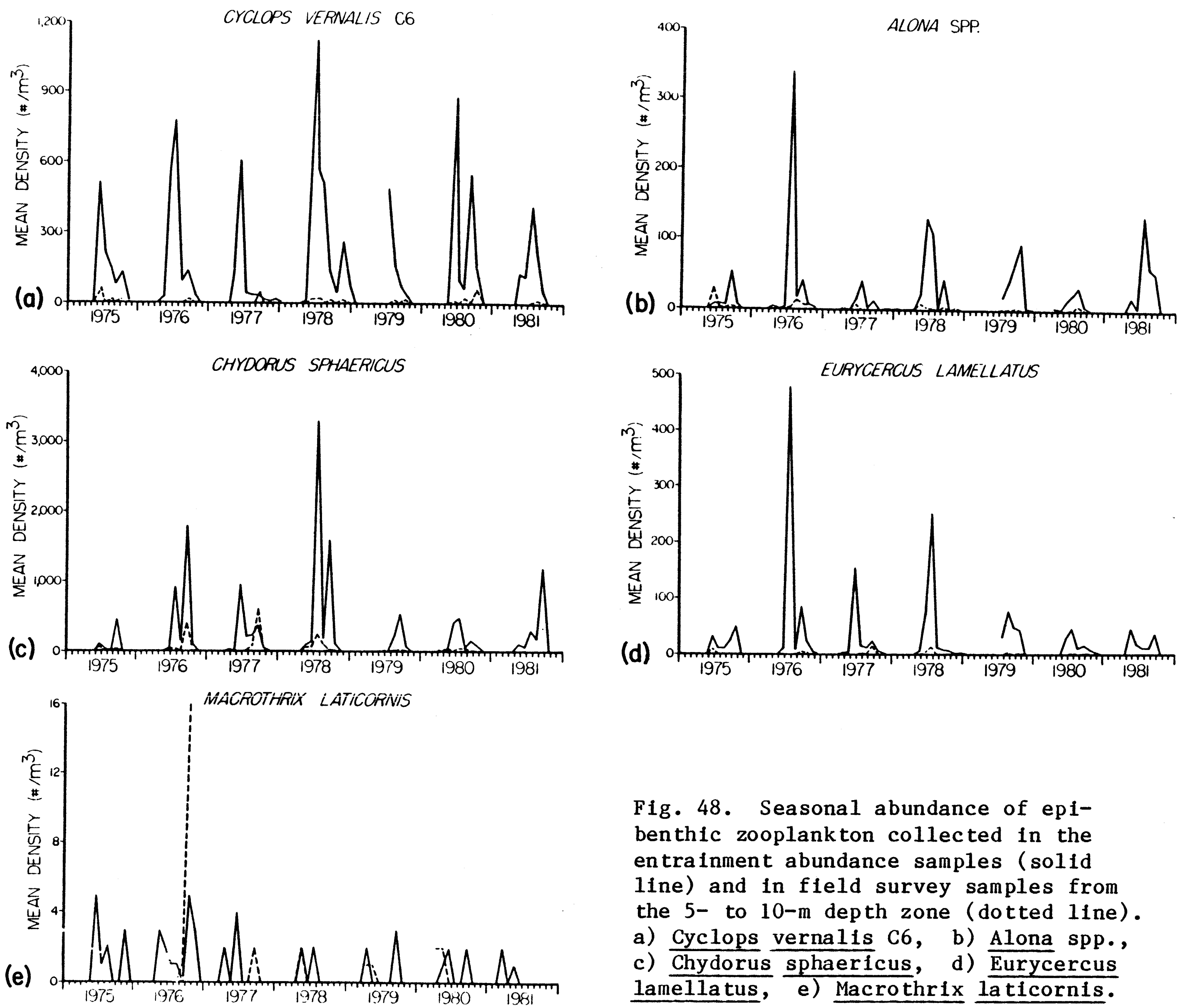


Fig. 48. Seasonal abundance of epibenthic zooplankton collected in the entrainment abundance samples (solid line) and in field survey samples from the 5- to 10-m depth zone (dotted line). a) Cyclops vernalis C6, b) Alona spp., c) Chydorus sphaericus, d) Eurycercus lamellatus, e) Macrothrix laticornis.

$33/m^3$, $10/m^3$, and $6/m^3$ for Eurycercus sp., and $195/m^3$, $630/m^3$, $158/m^3$, and $73/m^3$ for adult C. vernalis.

DISCUSSION

In an earlier report, Evans et al. (1978a) stated that it was unlikely that losses of zooplankton due to plant pasage would have an adverse effect on water or sediment quality in the vicinity of the plant. This hypothesis was based on a comparison of the estimated depositional rate of plant-killed zooplankton to the natural depositional rate. Assuming an average one-unit operation loss of 412 kg dry wt. zooplankton/month over a depositional area of 2.2 km^2 gave an estimated depositional rate of 6.2 mg/m^2/day. This compared with an estimated natural depositional rate of 2 to 4 gm/m^2/day, i.e., 0.2% of the estimated natural rate.

In 1977 and 1978, Evans et al. (1982) calculated a maximum estimated loss due to plant passage of 1,232 kg/month. While higher than the previous value, it still suggested that deposition of plant-killed zooplankton should have only a minimal effect on water quality in the vicinity of the plant. The maximum estimated zooplankton loss observed during the entire 1975 to 1982 study was 4,482 kg/month, resulting in an estimated maximum depositional rate that was only 2% of the estimated natural rate. Thus, deposition of zooplankton killed by plant passage appears to be small, adding little to the natural deposition which occurs in the area. Furthermore, lake currents prevent the net accumulation of such detrital material. A spatial-detailed study of epibenthic and benthic community structure in the vicinity of the plant (July 1980) confirmed that these invertebrates were not significantly affected by plant operation (Evans 1984).

The entrainment program provided detailed information on the short-term variability in zooplankton abundances. These data reveal fairly large variability in taxa abundances from one week to the next. This indicates that a single cruise conducted in a month does not provide a precise population estimate for that month. Thus, caution must be exercised in interpreting differences between individual cruises conducted in successive years. Furthermore, these observations illustrate the necessity for environmental impact studies to include more than one year of pre-impact investigation.

The results of our study indicate that the intake of the Donald C. Cook Nuclear Plant can serve as a representative sampling location for investigating long-term trends in zooplankton population trends in the inshore region. Correlations between euplanktonic taxa abundances in the cooling waters and in the inshore region were statistically significant and generally were high. Differences in abundance estimates between the intake and the inshore region were not statistically significant.

Epibenthic and benthic microcrustaceans generally occurred in higher concentrations in the cooling waters than in the intake. These differences do not appear to be attributable to any localized enrichment of these organisms in the vicinity of the plant. Rather, these animals probably were more readily entrained into the power plant than collected by the plankton net used for survey cruises. This net generally did not sample the lower meter of the water column where epibenthic microcrustaceans are abundant (Evans and Stewart 1977, Evans 1984). Thus, intake sampling may provide a more representative estimate of integrated water column microcrustacean community structure than lake surveys (Evans and Flath 1984).

Cyclops bicuspidatus thomasi often occurred in higher concentrations in the intake waters than in the inshore region. This species is a significant component of the epibenthic community (Evans and Stewart 1977, Evans 1984) in addition to being a major component of the euplankton (Evans et al. 1980). The largest difference between intake and inshore region abundance estimates occurred in late spring and early summer. This suggests that epibenthic adults were abundant during these seasons. Furthermore, seasonal population dynamics of epibenthic and euplanktonic adults may differ as is suggested by the relatively low correlation between intake and inshore region abundance estimates for this taxon. Relatively high concentrations of copepod nauplii in the cooling waters during spring and summer months may have originated from the reproductive activities of epibenthic *Cyclops bicuspudatus thomasi* and other such copepods.

Intake sampling has been used to document long-term changes in Great Lakes phytoplankton populations (Damann 1960, Davis 1964, Nicholls et al. 1977, Danforth and Ginsberg 1980). The results of this study suggest that intakes also can be used to investigate long-term trends in zooplankton populations (Evans and Flath 1984). Intake sampling avoids the high costs of vessel operation and is feasible throughout the year. Furthermore, since diel variations in taxa abundance generally were not statisically significant, it should be sufficient to collect a replicated sample at a single time period (e.g., noon).

CONCLUSIONS

The general conclusion of the 8-year operational (1975-1982) study evaluating the impact of the Donald C. Cook Nuclear Plant on zooplankton populations in southeastern Lake Michigan is that Unit 1 and Unit 2 operation did not adversely affect the maintenance of a balanced indigenous population in the discharge area. Furthermore, on most occasions, the condenser cooling system operated under conditions which minimized zooplankton mortality. Thus, the power plant appears to have met the general requirements of Sections 316(a) and 316(b) of Public Law 92-500 with respect to the zooplankton community.

Mortalities due to plant passage generally were low; net mortalities averaged less than 4% for total zooplankton. Calanoid copepods, *Daphnia* spp., and *Eubosmina coregoni* were the major taxa which appeared to be most sensitive to plant passage. Relatively low ΔT's (<12 C°) and low discharge water temperatures (<35°C) were of major importance in reducing thermal stresses experienced by plant-entrained zooplankton. Previous studies reported in Section 3 suggest that zooplankton mortalities at the Donald C. Cook Nuclear Plant would increase substantially were the plant to operate at greater ΔT's or increase ambient water temperatures to above 35°C.

Subsurface discharge jets promoted rapid mixing and cooling of condenser-passed water. The thermal plume was generally small (<3 km^2) and only 1 to 2 C° above ambient temperatures. This rapid cooling minimized thermal stresses experienced by plume-entrained zooplankton. It is highly unlikely that short-term exposures (less than 3 hours) to temperatures 1 to 2 C° above ambient could have any significant effect on zooplankton populations.

Intense vertical mixing in the vicinity of the discharge jets prevented the water column loss (by sinking) of plant-killed zooplankton. Consequently, these losses could not be detected in samples collected in the vicinity of the discharge jets, immediately preserved, and later examined in the laboratory. While significant settling of dead zooplankton probably occurred a few hundred meters away from the discharge jets, condenser-passed water and zooplankton were so diluted at these locations that these losses were not statistically detectable given the inherent variability in zooplankton populations and the limited number (2-3) of stations in the thermal plume. Lake currents transport zooplankton several kilometers a day (under average current velocities), constantly replenishing zooplankton standing stocks in the discharge area.

There were some differences in zooplankton populations between the preoperational and operational periods. The factors causing these differences remain under investigation and are not dealt with in this operational report. Such differences appear, in large measure, to be due to major changes in fish community structure which began to occur approximately in 1978 and intensified through the early 1980s. Zooplankton (and fisheries) monitoring studies conducted at the Donald C. Cook Plant provide excellent documentation of these trends.

REFERENCES

Ayers, J. C. 1975. The phytoplankton of the Cook Plant monthly minimal surveys during the preoperational years 1972, 1973, and 1974. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 59.

--------, D. C. Chandler, G. H. Lauff, C. F. Powers, and E. B. Hensen. 1958. Currents and water masses of Lake Michigan. Univ. Michigan, Great Lakes Res. Inst. Pub. 3.

--------, A. E. Strong, C. F. Powers, and R. Rossmann. 1967. Benton Harbor Power Plant Limnological Studies. Pt. II. Studies of local winds and alongshore currents. Univ. Michigan, Great Lakes Res. Div., Spec. Rep. 44.

Beeton, A. M. 1969. Changes in the environment and biota of the Great Lakes, pp. 150-187. In: Eutrophication: Causes, Consequences, Correctives. Nat. Acad. Sci. Publ. 1700.

Brandlova, J., Z. Brandl, and C. H. Fernando. 1972. The Cladocera of Ontario with remarks on some species and distributions. Can. J. Zool. 50:1373-1403.

Brauer, G. A., W. M. Neill, and J. J. Magnuson. 1974. Effects of a power plant on zooplankton distribution and abundance near plant's effluent. Water Res. 8:485-489.

Brooks, J. L. 1957. The Systematics of North American Daphnia. New Haven, Connecticut: Yale University Press. University Press.

--------. 1959. Cladocera, pp. 587-656. In: W. T. Edmonson (ed.) Fresh-water Biology 2nd ed. John Wiley and Sons, New York.

--------. 1968. The effects of prey size selection by lake planktivores. Syst. Zool. 17:272-291.

--------. 1969. Eutrophication and changes in the composition of the zooplankton, pp. 236-255. In: Eutrophication: Causes, Consequences, Correctives. Nat. Acad. Sci. Publ. 1700.

--------, and S. I. Dodson. 1965. Predation, body size, and composition of plankton. Science 250:28-35.

Brown, L. A. 1929. The natural history of cladocerans in relation to temperature. Amer. Nat. 63:(686)248-264.

--------, and W. J. Crozier. 1927-1928. The rate of killing of cladocerans at higher temperatures. J. Gen. Physiol. 11:25-36.

Carpenter, E. J., B. B. Peck, and S. J. Anderson. 1974. Survival of copepods passing through a nuclear power station on northeastern Long Island Sound, USA. Mar. Biol. 24:49-55.

Chapra, S. C., and A. Robertson. 1977. Great Lakes eutrophication: the effect of point source control of total phosphorus. Science 196:1448-1449.

Christie, W. J. 1974. Changes in the fish species composition of the Great Lakes. J. Fish Res. Board Can. 31(5):827-854.

Cochran, W. G. 1977. Sampling Techniques. John Wiley Sons, New York. 428 pp.

Coker, R. E. 1934. Reaction of some freshwater copepods to high temperatures. J. Elisha N. Mitchell Sci. Soc. 50:143-159.

Conover, W. J. 1971. Practical Nonparametric Statistics. Wiley, New York.

Damann, K. E. 1960. Plankton studies of Lake Michigan. II. Thirty-three years of continuous plankton and coliform bacteria data collected from Lake Michigan at Chicago, Illinois. Trans. Amer. Microsc. Soc. 79:397-404.

Danforth, W. F., and W. Ginsberg. 1980. Recent changes in the phytoplankton of Lake Michigan near Chicago. J. Great Lakes Res. 4:307-314.

Davies, R. M., and L. M. Jensen. 1974. Effects of entrainment of zooplankton in three mid-Atlantic power plants. Electric Power Research Institute. Palo Alto, California. Report No. 10.

--------, C. H. Hanson, and L. D. Jensen. 1976. Entrainment of estuarine zooplankton in a Mid-Atlantic power plant: Delayed effects, pp. 348-357. In: (ed.) G. W. Esch and R. W. McFarlane. Thermal Ecology II. Technical Information Center, Energy Research Development Center.

Davis, C. C. 1964. Evidence for the eutrophication of Lake Erie from phytoplankton records. Limnol. Oceanogr. 9:275-283.

Deevey, E. S., and G. B. Deevey. 1971. The American species of Eubosmina Seligo (Crustacea, Cladocera). Limnol. Oceanogr. 16:201-208.

Drost-Hansen, W. 1969. Allowable thermal pollution limits - a physico-chemical approach. Chesapeake Sci. 10:281-288.

Evans, M. S. 1975. The 1974 preoperational zooplankton investigations relative to the Donald C. Cook Nuclear Power Plant. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 58.

--------. 1981. Distribution of zooplankton population within and adjacent to a thermal plume. Can. J. Fish. Aquat. Sci. 38:441-448.

--------. 1984. Benthic and epibenthic (microcrustaceans, macrobenthos) community structure in the vicinity of a power plant, southeastern Lake Michigan. Verh. Internat. Verein. Limnol. 22:488-494.

--------. 1985. The morphology of Daphnia pulicaria, a species newly dominating the offshore southeastern Lake Michigan summer Daphnia community. Trans. Amer. Microsc. Soc. 104:223-231.

--------. 1986. Recent declines in zooplankton populations in the inshore region of Lake Michigan: probable causes and consequences. Can. J. Fish. Aquat. Sci. 43:154-159.

--------, and L. E. Flath. 1984. Intakes as sampling locations for investigating long-term trends in zooplankton populations. Can. J. Fish Aquat. Sci. 41:(10)1513-1518.

--------, and D. J. Jude. 1986. Recent shifts in Daphnia community structure in southeastern Lake Michigan: A comparison of the inshore and offshore. Limnol. Oceanogr. 31:56-67.

--------, and D. W. Sell. 1983. Zooplankton sampling strategies for environmental studies. Hydrobiologia 99:215-223.

--------, and D. W. Sell. 1985. Mesh size and collection characteristics of 50-cm diameter conical plankton nets. Hydrobiologia 122:97-104.

--------, and J. A. Stewart. 1977. Epibenthic and benthic micro- crustaceans (copepods, cladocerans, ostracods) from a nearshore area in southeastern Lake Michigan. Limnol. Oceangr. 22:1059-1066.

--------, T. E. Wurster, and B. E. Hawkins. 1978a. The 1975 and 1976 operational zooplankton investigations relative to the Donald C. Cook Nuclear Power Plant, with tests for plant effects (1971-1976). Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 64.

--------, B. E. Hawkins, and T. E. Wurster. 1978b. Effects of the Donald C. Cook nuclear power plant on zooplankton in southeastern Lake Michigan, pp. 125-139. Fourth National Workshop on Entrainment and Impingement, December 5-7, 1977.

--------, B. E. Hawkins, and D. W. Sell. 1980. Seasonal features of zooplankton assemblages in the nearshore area of southeastern Lake Michigan (1971-1977). J. Great Lakes Res. 6:275-289.

--------, D. W. Sell, and D. I. Page. 1982. Zooplankton studies at the Donald C. Cook Nuclear Power Plant: Comparisons of preoperational (1972-1974) and operational (1975-1978) population characteristics. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 89.

--------, G. W. Warren, and D. I. Page. 1986. The effects of power plant passage on zooplankton mortalities; eight years of study at the Donald C. Cook Nuclear Plant. Water Res. 20:725-734.

Galbraith, M. G., Jr. 1967. Size-selective predation on Daphnia by rainbow trout and yellow perch. Trans. Amer. Fish. Soc. 96:1-10.

Gannon, J. E., and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Am. Microsc. Soc. 97:16-35.

Grogg, C. V. 1977. Morphological variation in the "Pulex" group of the genus Daphnia. M.A. thesis. Ball State Univ., Muncie, Indiana. 38 pp.

Haney, J. F., and D. J. Hall. 1970. Sugar-coated Daphnia: a preservation technique for Cladocera. Limnol. Oceanogr. 18:331-333.

Hawkins, B. E., and M. S. Evans. 1979. Seasonal cycles of zooplankton biomass in southeastern Lake Michigan. J. Great Lakes Res. 5:256-263.

Heinle, D. R. 1969. Temperature and zooplankton. Chesapeake Sci. 10:186-209.

Hrbacek, J. 1962. Species composition and the amount of the zooplankton in relation to the fish stock. Rozpravy CSAV, Rada Mat. a prir. Ved. 72(10):1-116.

Icanberry, J. W., and J. R. Adams. 1974. Zooplankton survival in cooling water systems of four thermal power plants on the California coast. In: (Ed.). L. D. Jensen. Proceedings of the Second Workshop on Entrainment and Intake Screening. Electric Power Research Institute. Palo Alto, California.

Indiana & Michigan Electric Power Company. 1976. Donald C. Cook Nuclear Power Plant, Units 1 and 2. 1976. Report of the performance of thermal plume areal measurements. Vols. 1 and 2.

Industrial Bio-Test Laboratories, Inc. 1974a. Thermal tolerance limit determinations for Lake Michigan zooplankton. Project XVII-B IBT No. 643-01862. July 1972 to March 1973. Report to Commonwealth Edison Company.

--------. 1974b. Environmental monitoring in Lake Michigan near Zion and Waukegan generating stations. January 1972 through December 1972. Vol 2. Report to Commonwealth Edison Company.

--------. 1975. Operational environmental monitoring program of Lake Michigan near Kewaunwee nuclear power plant: Chemical and biological studies. Fourth annual report. January to December 1974. Report to Wisconsin Public Service Corporation. Wisconsin Power and Light Company. Madison Gas and Electric Company.

Johnston, E. M. 1973. Effect of a thermal discharge on benthos populations, statistical methods for assessing the impact of the Cook Nuclear Plant. Benton Harbor Limnological Studies, Part XVIII. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 44.

Jude, D. J., F. J. Tesar, J. A. Dorr III, T. J. Miller, P. J. Rago, and D. J. Stewart. 1975. Inshore Lake Michigan fish populations near the Donald C. Cook Nuclear Plant. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 52.

Krezoski, J. R. 1969. Some effects of power plant waste heat discharge on the ecology of Lake Michigan. Benton Harbor Plant Limnological Studies. Part 3. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 44.

Lanner, M., and B. Pejler. 1973. The effect of cooling water discharges on zooplankton in a bay of Lake Malaren. Instit. of Freshwater Res., Drottningholm. Report 53:31-33.

Limnetics, Inc. 1975. An environmental study of the ecological effects of thermal discharge from the Point Beach Nuclear Plant. Nov. 1973 through October 1974. Annual Report No. 2., Vol. 2. Report to the Wisconsin Power Company and Wisconsin Michigan Power Co.

--------. 1976. An environmental study of the ecological effects of thermal discharge from the Point Beach Nuclear Plant. Nov. 1974 through October 1975. Annual Report No. 3. Report to Wisconsin Power Company and Wisconsin Michigan Power Co.

Makarewicz, J. C. and R. I. Baybutt. 1981. Long-term (1927-1978) changes in the phytoplankton community of Lake Michigan at Chicago. Bull. Torrey Bot. Club 108:240-254.

Marcy, B. C. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. J. Fish. Res. Board Can. 30:1195-1203.

Mathur, D., T. W. Robbins, and E. J. Purdy, Jr. 1980. Assessment of thermal discharge on zooplankton in Conowingo Pond, Pennsylvania. Can. J. Fish. Aquat. Sci. 37:937-944.

McMahon, J. W., and A. Docherty. 1975. Effects of heat enrichment on species succession and primary production in freshwater plankton, pp. 529-546. In: Environmental effects of cooling systems at nuclear power plants. International Atomic Energy Agency, Vienna.

McNaught, D. C. 1975. A hypothesis to explain the succession from calanoids to cladocerans during eutrophication. Verh. Internat. Verein. Limnol. 19:724-731.

--------, and M. Buzzard. 1973. Changes in zooplankton populations in Lake Ontario (1939-1972), pp. 76-86. In: Proc. 15th Conf. Great Lakes Res. Internat. Assoc. Great Lakes Res.

Mozley, S. C. 1973. Study of benthic organisms, pp. 178-249. In: J. E. Ayers and E. Seibel. Benton Harbor Power Plant Limnological Studies. Part XIII. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 44.

--------. 1974. Preoperational studies of benthic macroinvertebrates in Lake Michigan near the Cook nuclear plant, pp. 5-138. In: J. C. Ayers and E. Seibel. The biological, chemical, and physical character of Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 51.

Nicholls, K. H., D. W. Standen, G. J. Hopkins, and E. C. Carney. 1977. Declines in the near-shore phytoplankton of Lake Erie's western basin since 1971. J. Great Lakes Res. 3:72-78.

Patalas, K. 1970. Primary and secondary production in a lake heated by thermal power plant. Proc. Inst. Envir. Sciences 9:267-271.

--------. 1972. Crustacean plankton and the eutrophication of the St. Lawrence Great Lakes. J. Fish. Res. Board Can. 29:1451-1462.

Pederson, G. L., E. B. Welch, and A. H. Litt. 1976. Plankton secondary productivity and biomass; their relation to lake trophic state. Hydrobiologia 50:129-144.

Pennak, R. W. 1963. Species identification of the freshwater cyclopoid Copepoda of the United States. Trans. Amer. Microsc. Soc. 82:353-359.

--------. 1978. Fresh-water invertebrates of the United States. 2nd Ed. New York. John Wiley & Sons, New York. 818 pp.

Raj, D. 1968. Sampling Theory. McGraw-Hill, Inc., New York. 302 pp.

Reeve, M. R. 1970. Seasonal changes in the zooplankton of south Biscayne Bay and some problems of assessing the effects on the zooplankton of natural and artificial thermal and other fluctuations. Bull. Mar. Sci. 20:894-921.

Rossmann, R. 1975. Chemistry of nearshore surficial sediments from southeastern Lake Michigan. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 57.

Roth, J. C. 1973. Study of the zooplankton, pp. 77-168. In: J. C. Ayers and E. Seibel. Benton Harbor Limnological Studies. Pt. XIII. Univ. of Michigan, Great Lakes Res. Div. Spec. Rep. 44.

Scavia, D., G. L. Fahnensteil, M. S. Evans, D. J. Jude, and J. T. Lehman. 1986. Influence of salmonid predation and weather on long-term water quality trends in Lake Michigan. Can. J. Fish. Aquat. Sci. 43:435-443.

Seigel, S. 1956. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill, New York.

Sell, D. W., and M. S. Evans. 1982. A statistical analysis of subsampling and an evaluation of the Folsom plankton splitter. Hydrobiologia 94:223-230.

Standke, S. J., and B. P. Monroe. 1981. Forms of physical damage and related effects of zooplankton as a result of entrainment at Nanticoke G. S. 1976. J. Great Lakes Res. 7:136-143.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York.

Stemberger, R. S. 1979. A Guide to Rotifers of the Laurentian Great Lakes. Report no. EPA-600/4-79-021. U.S. Environmental Protection Agency.

--------, and M. S. Evans. 1984. Rotifer seasonal succession and copepod predation in Lake Michigan. J. Great Lakes Res. 10:417-428.

Texas Instruments Incorporated. 1975. 1974-1975 Annual Report. Bailly nuclear site 1 encompassing April 1974-February 1975. Report to Northern Indiana Public Service Co.

Torke, B. G. 1975. The population dynamics and life history of crustacean zooplankton at a deep-water station in Lake Michigan. Ph.D. thesis, Univ. Wisconsin, Madison, Wisc.

Tressler, W. L. 1959. Ostracoda, pp. 657-734. In: W. T. Edmondson (ed.), Fresh-water Biology, 2nd ed. John Wiley and Sons, New York.

United States Atomic Energy Commission. 1973. Final environmental statement related to the operation of the Donald C. Cook nuclear power plant. Units 1 and 2. Indiana and Michigan Electric Company and Indiana and Michigan Power Company. Docket Nos. 50-315 and 50-316.

United States Department of the Interior. 1968. Water quality investigations, Lake Michigan basin: physical and chemical quality conditions. FWPCA, Chicago.

Warren, G. J., M. S. Evans, D. J. Jude, and J. C. Ayers. 1986. Seasonal variation in copepod size: effects of temperature, food abundance, and vertebrate predation. J. Plankton Res. 8:841-854.

Wells, L. 1960. Seasonal abundances and vertical movements of plankton crustacea in Lake Michigan. U.S. Fish Wildl. Serv., Fish Bull. 60:343-369.

--------. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U. S. Fish. Wildl. Serv., Fish. Bull. 67:1-15.

--------. 1970. Effects of alewife predation on zooplankton populations in Lake Michigan. Limnol. Oceanogr. 15:556-565.

Wetzel, D. L. 1975. Zooplankton entrainment. In: Industrial Bio-Test Laboratories, Inc. Operational environmental monitoring program of Lake Michigan near Kewaunee nuclear power plant: chemical and biological studies. Fourth annual report. January-December 1974. Report to Wisconsin Public Service Corporation. Wisconsin Power and Light Company. Madison Gas and Electric Company.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co. Philadelphia.

Whitehouse, J. W. 1971. Some aspect of the biology of Lake Trawsfyndd: a power station cooling pond. Hydrobiologia 38:253-288.

Wilson, M. S. 1959. Free-living Copepoda: Calanoida, pp. 738-794. In: Fresh-water Biology 2nd ed. John Wiley and Sons, New York.

--------, and H. C. Yeatman. 1959. Free-living Copepoda: Harpacticoida, pp. 815-861. In: Fresh-water Biology 2nd ed. John Wiley and Sons, New York.

Yeatman, H. C. 1959. Free-living Copepoda: Cyclopoida, pp. 794-814. In: Fresh-water Biology 2nd ed. John Wiley and Sons, New York.

Yocum, W. L., M. S. Evans, and B. E. Hawkins. 1978. A comparison of pump sampling systems for collecting live zooplankton. Hydrobiologia 60:199-202.

Zaret, T. M. 1980. Predation and Freshwater Communities. Yale University Press.

--------, and J. S. Suffern. 1976. Vertical migration in zooplankton as a predation avoidance mechanism. Limnol. Oceanogr. 21:804-813.

Zhitenjowa, T. S., and J. I. Nikanorow. 1972. Der Einfluss des vom Konakowschen Warmekraftwerk abliessenden Warmwassers auf die biologischen Prozesse im Iwanjkowo-Stausee. Verh. Internat. Verein. Limnol. 18:833-836.